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FINAL

**Work Plan for a Demonstration of Remediation
by Natural Attenuation for Groundwater at OU 2**



**Hill Air Force Base
Ogden, Utah**

Prepared For:

**Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas**

and

**Hill Air Force Base
Ogden, Utah**

May, 1997

AQM01-01-0301

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FINAL

**WORK PLAN FOR A DEMONSTRATION OF
REMEDATION BY NATURAL ATTENUATION
FOR GROUNDWATER AT OU 2**

at

HILL AIR FORCE BASE, UTAH

May 1997

Prepared for:

**AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE
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ACRONYMS AND ABBREVIATIONS

°C	degrees centigrade
°F	degrees Fahrenheit
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
bgl	below ground level
BNAE	base-neutral acid-extractable
BTEX	benzene, toluene, ethylbenzene, xylenes
CA	chloroethane
CAH	chlorinated aliphatic hydrocarbon
CDP	Chemical Disposal Pit
cm/sec	centimeters per second
CPT	cone penetrometer test
CSR	CalScience Research, Inc.
DCA	dichloroethane
DCB	dichlorobenzene
DCE	dichloroethene
DO	dissolved oxygen
ES	Engineering-Science, Inc.
ft/day	feet per day
ft ² /day	square feet per day
ft/ft	feet per foot
ft/min	feet per minute
FTA	Fire Training Area
HARM	Hazardous Assessment Rating Methodology
HDPE	high density polyethylene
ID	inside diameter
IRP	Installation Restoration Program
IWTP	industrial wastewater treatment plant
JMM	James M. Montgomery, Consulting Engineers, Inc.
L/min	liters per minute
LCS	laboratory control sample
LF	Landfill
LMB	laboratory method blank
LNAPL	light non-aqueous phase liquid
LTM	long-term monitoring
MCL	maximum concentration limit
MEK	methyl ethyl ketone
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
msl	mean sea level

mV	millivolt
NPL	National Priority List
NRMRL	National Risk Management Research Laboratory
OD	outside diameter
ORD	Office of Research and Development
ORP	oxidation-reduction potential
OSWER	Office of Solid Waste and Emergency Response
OU	Operable Unit
OVM	Organic Vapor Meter
Parsons ES	Parsons Engineering Science, Inc.
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PID	photoionization detector
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
Radian	Radian Corporation
RAP	remedial action plan
redox	reduction/oxidation
RI	Remedial Investigation
RNA	remediation by natural attenuation
SAIC	Science Applications International Corporation
SDWA	Safe Drinking Water Act
TCA	trichloroethane
TCE	trichloroethene
TCLP	toxicity characteristic leaching procedure
TD	total depth
TDS	total dissolved solids
TOC	total organic carbon
TPH	total petroleum hydrocarbons
USAF	United States Air Force
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UST	underground storage tank
VC	vinyl chloride
VOC	volatile organic compound
WOST	waste oil storage tank
WPOP	waste phenol/oil pit

SECTION 1

INTRODUCTION

This work plan (WP) was prepared by Parsons Engineering Science, Inc. (Parsons ES) to define the scope of work (SOW) and procedures required to demonstrate that remediation by natural attenuation (RNA) is occurring in groundwater contaminated with chlorinated aliphatic hydrocarbons (CAHs) at Operable Unit 2 (OU 2) at Hill Air Force Base (AFB), Utah. To meet this goal, this WP presents a preliminary conceptual model, based on a review of available data, and provides suggested protocols to fill the identified data gaps necessary to develop a more thorough conceptual model of groundwater flow and RNA at OU 2.

For the purposes of this WP, RNA is defined as a management strategy that relies on natural mechanisms to bring about a reduction in the total mass of contamination in the subsurface, and to control receptor exposure risks associated with this contamination. Natural attenuation is defined by the United States Environmental Protection Agency (USEPA) Offices of Research and Development (ORD) and Solid Waste and Emergency Response (OSWER), as follows:

The biodegradation, dispersion, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.

As suggested by this definition, there are destructive and non-destructive mechanisms of natural attenuation. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. During biodegradation, indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients. Patterns and rates of natural attenuation can vary markedly from site to site depending on governing physical and chemical processes.

RNA provides advantages over other remedial options for the following reasons:

- Contaminants are transformed to innocuous byproducts (e.g., carbon dioxide, ethene, or water), while other remedial options may result in contaminant

transformation from one phase to another, or contaminant transport to another location within the environment;

- Current engineered remedial options (e.g., pump-and-treat technologies) may be energy-intensive and generally are not as effective as RNA in reducing residual contamination;
- Engineered remedial technologies may pose a greater risk to potential receptors than RNA (i.e., the use of engineered remedial technologies may disturb the existing contaminant equilibrium, increasing contaminant mobility in the subsurface, resulting in the transfer of contaminants to non-contaminated media, etc.);
- The RNA process is non-intrusive, and allows continuing use of infrastructure during remediation; and
- RNA is less costly than most conventional remedial technologies.

Natural attenuation has the following potential limitations:

- The success of natural attenuation is controlled by natural conditions including local hydrogeologic conditions [e.g., changes in groundwater gradients/velocity, potential of hydrogen (pH), electron acceptor concentrations, electron donor availability, potential future contaminant releases, oxidation/reduction potential, etc.] and these conditions may be influenced by human activities;
- Aquifer heterogeneity may complicate site characterization, and evaluation, and may influence the nature of RNA processes at a given site;
- Microorganisms capable of biodegradation must be present;
- Restoration of contaminated groundwater using RNA is dependent on the nature of contamination, aquifer characteristics, environmental conditions, etc., and may require extended periods of time;
- Some intermediate products of biodegradation (e.g., vinyl chloride) are more toxic than the original contaminant; and
- Alternate present and potential future sources of contamination may contribute to the total mass of contamination present at a site, and may affect the time required to restore contaminated groundwater.

1.1 PURPOSE AND SCOPE OF CURRENT WORK PLAN

The purpose of this WP is to outline the procedures necessary to obtain data to demonstrate that RNA with long-term monitoring (LTM) is a viable method of

remediating contaminated groundwater at OU 2. The main objective of the demonstration is to provide solid evidence of the RNA of dissolved CAHs, so that this information can be used to develop an effective groundwater remediation strategy in which RNA is major part of the overall remediation plans for OU 2. Although the hydrogeologic and analytical data methods described in this WP may be adequate to evaluate various other remedial options, these data are intended to evaluate contaminant transport and natural attenuation, and may not provide sufficient data to evaluate other options adequately. The results are expected to support RNA with LTM as a preferred method of remediation of CAH-contaminated groundwater at OU 2.

This WP was developed through discussions that included representatives from Hill AFB, the State of Utah Department of Environmental Quality (CERCLA and RCRA divisions), the USEPA - Region VIII, the Air Force Center for Environmental Excellence (AFCEE), the USEPA National Risk Management Research Laboratory (NRMRL), Parsons ES, and Hill AFBs' prime consultants. A workshop on natural attenuation of chlorinated solvents was conducted on 3 April 1996 and included representatives from these groups. In addition, an expert from Beak Consultants and Utah State University participated. The purpose of this workshop was to evaluate the site-specific approach for RNA at various sites, including OU 2, based on a review of available site characterization data. The final portion of the discussion was directed toward establishing a conceptual model of each OU and recommendations for possible action, including suggested data collection that might be used to fill "data gaps" associated with a particular OU.

This WP was prepared for AFCEE and Hill AFB. It is not intended to fulfill the requirements of a contamination assessment report, a remedial action plan (RAP), or any other document specified in federal or state regulations. The information contained herein is provided for the use of Hill AFB, and state and federal regulatory agencies. This information is intended to be used for future decision-making at OU 2.

This WP consists of six sections, including this introduction. Section 2 presents a review of available, previously reported data for OU 2 and the surrounding area, where it is pertinent to the evaluation of RNA, and the development of the preliminary conceptual model for OU 2. Section 3 describes the proposed sampling strategy and procedures to be used for the collection of additional data necessary to evaluate RNA and refine the conceptual model for OU 2. Section 4 presents proposed quality assurance/quality control (QA/QC) measures. Section 5 describes data analysis and remedial option evaluation. Section 6 contains references used in preparing this document. There are two appendices included with this WP. Appendix A contains selected analytical data from previous work performed at OU 2. Appendix B contains a listing of analytical methods and containers, data use, and sampling and laboratory requirements for soil and water-matrix analytical samples.

1.2 BACKGROUND

Hill AFB is located east of US Interstate 15, approximately 25 miles north of Salt Lake City, Utah (Figure 1.1). Since 1981, as part of a base-wide Installation Restoration Program (IRP), a number of investigations were performed at former waste disposal sites. The Phase I - IRP investigation identified 13 sites that had the potential to cause environmental degradation. Utah Biomedical Testing Laboratory (UBTL), Inc., and Radian Corporation (Radian) initiated a Phase II, Stage 1 investigation in 1982 to evaluate whether any of the 13 sites were contamination source areas. Radian and Science Applications International Corporation (SAIC) completed the Phase II, Stage II (SI) Field evaluation in 1988. The purpose of the SI study was to further define the nature and extent of contamination. As a result of this investigation, Hill AFB was added to the National Priorities List (NPL) in July 1987. Of the original 13 potential sites, seven OUs were explicitly identified in a Federal Facilities Agreement (FFA), signed by Hill AFB, the USEPA (Region VIII), and the State of Utah Division of Environmental Health (now the Department of Environmental Quality).

OU 2 is one of eight potential source sites (Operable Units OU 1 through OU 8) being investigated for contamination resulting from past hazardous waste disposal practices. OU 2 has been defined in the Federal Facilities Agreement (FFA) to include former Chemical Disposal Pit 3 and the area adjacent to Perimeter Road, along the eastern boundary Hill AFB, south of the Davis-Weber Canal.

Chemical Disposal Pit 3 is considered the contaminant source area at OU 2 and consists of two parallel, unlined earthen trenches located approximately 50 to 75 feet west of Perimeter Road (Figure 1.2). The trenches are approximately 50 feet and 100 feet in length, and were reportedly used for the disposal of spent liquid degreasing solvents and wastes from metal plating processes. The reported dates of disposal were 1967 to 1975. The quantities of materials disposed within the trenches is not known. However, based on the results of intrusive investigation near the trenches and chemical usage at the Base, trichloroethene (TCE) appears to have been the primary CAH disposed in the trenches. Tetrachloroethene (PCE), and trichloroethane (TCA) are also present, but at lesser amounts.

1.3 SITE REMEDIATION ACTIVITY

Remediation at OU 2 consists of a drainage gallery with on-site treatment in the downgradient, off-base area, a solvent recovery system (SRS) near the Chemical Disposal Pit 3 source area, and current construction of a containment wall between the trenches and perimeter road. Approximately 30,000 gallons of dense non-aqueous phase liquid (DNAPL) has been recovered thus far with the SRS system (natural attenuation workshop notes, 3 April 1996).

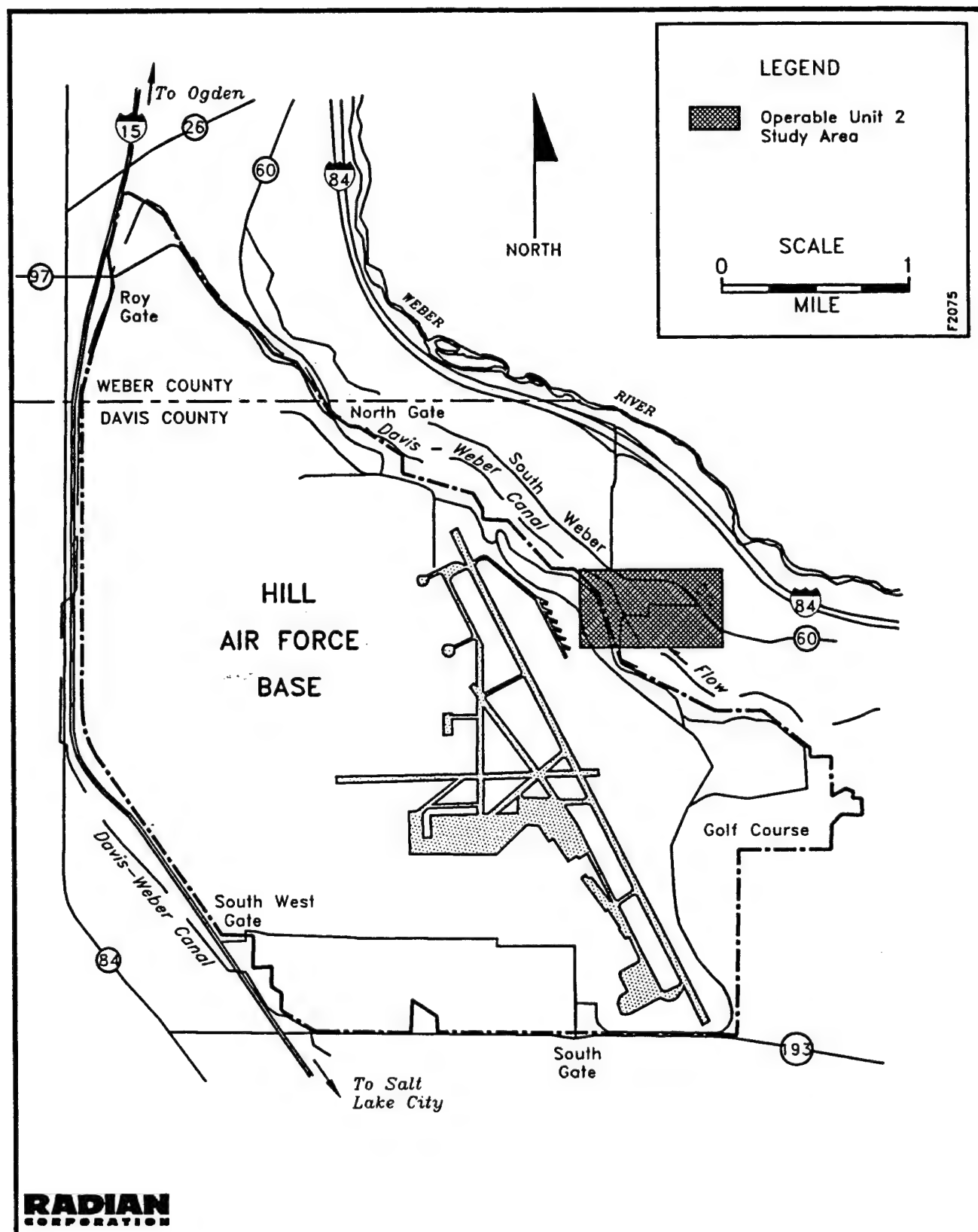


Figure 1.1 Hill AFB Area with the Location of Operable Unit 2

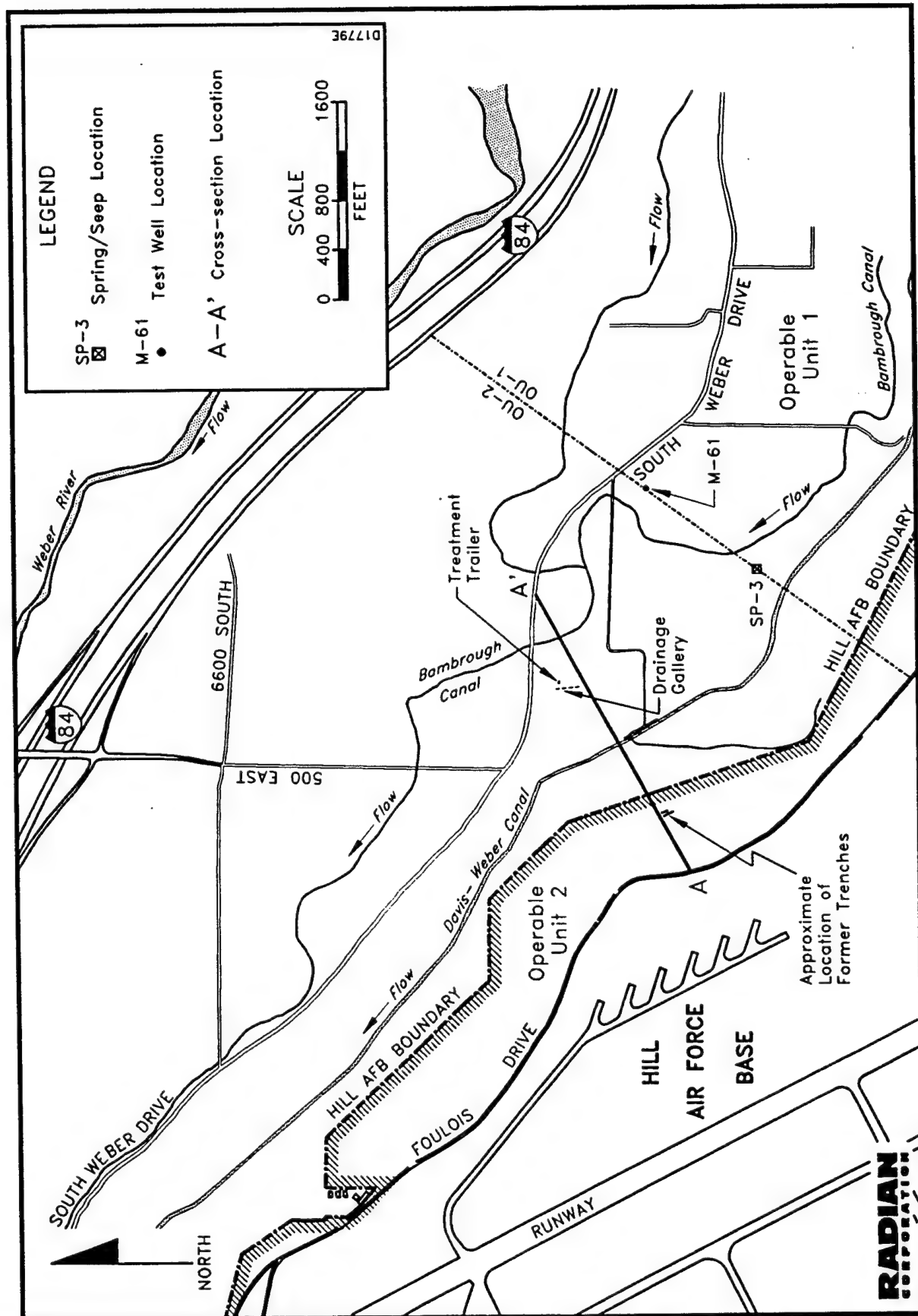


Figure 1.2 Features of Operable Unit 2 at Hill AFB

SECTION 2

DATA REVIEW AND CONCEPTUAL MODEL DEVELOPMENT

Existing site-specific data were reviewed to develop a preliminary conceptual model of RNA for groundwater at OU 2. Section 2.1 presents a synopsis of available site characterization data. Section 2.2 presents the preliminary conceptual model of natural attenuation and fate processes that were developed based on these data. The conceptual model guided the development of sampling locations and analytical data requirements needed to support the modeling efforts and to evaluate RNA. Proposed sampling locations and the analytical data requirements and sampling protocols are discussed in Section 3.

2.1 DATA REVIEW

The following sections are based on review of data from the following sources:

- Final Remedial Investigation (RI) Report for Operable Unit 2 (Radian, 1992);
- Addendum to the Remedial Investigation Report for Operable Unit 2 (Radian, 1994);
- Operable Unit 2 Groundwater Sampling, May 1993-February 1995 (CH₂M Hill, 1995); and,
- Operable Unit 2 Groundwater Sampling, April 1995-March 1996 (CH₂M Hill, 1996)

2.1.1 Physiography, Topography, Surface Hydrology, and Climate

Hill AFB is located in northern Utah, approximately 25 miles north of Salt Lake City and 5 miles south of Ogden. The Base contains 6,666 acres in Davis and Weber Counties. The western boundary of the Base is near Interstate 15, and the southern boundary is near State Route 193. The northern and northeastern perimeters of the Base are bounded by the Davis-Weber Canal, a privately-owned irrigation canal. The Wasatch Mountain Range is about 4 miles to the east, and the Great Salt Lake is about 6 miles to the west. The Base is located within the Bonneville Basin subsection of the Great Basin section of the Basin and Range physiographic province.

Hill AFB is located on a plateau which rises approximately 300 feet above the Weber River Valley on the east and approximately 50 to 100 feet above the towns of Sunset and Clinton on the west. Except for areas dissected by erosion, most of HAFB is relatively level, ranging in altitude between approximately 4,550 and 4,800-feet above mean sea level (msl) with higher areas near 4,900-feet in the far eastern portion of the Base near the golf course area.

Chemical Disposal Pit 3, the identified contaminant source area at OU 2, is situated about 500 feet downhill (horizontal distance) and northeast of the margin of the terrace and hillside at an approximate ground surface elevation of 4,700-feet above msl. The surface topography slopes abruptly and steeply to the northeast below the disposal pit until leveling at approximately 4,440-feet above msl on the flood-plain of the Weber River. Springs or seeps discharge at off-base locations along the hillside with a most occurring between 4,600 and 4,480 feet above msl.

Surface drainage at OU 2 is generally to the northeast, toward the off-base areas. Some drainage is intercepted by the Davis-Weber Canal, which is located approximately 800 feet downhill (horizontal distance) and northeast of the source area and flows to the northwest, adjacent to the northeast boundary of HAFB. Shallow groundwater flow is influenced by the presence of this canal, the Bambrough canal, and several drains. The water source for the canals is the Weber River; both are intermittently active, and lose water to the shallow groundwater when they are flowing (Radian, 1992).

The climate of Hill AFB is semi-arid. Mean annual precipitation is just over 18 inches, and annual evaporation is approximately 45 inches (Feth *et al.*, 1966). At Ogden, just north of Hill AFB, the average temperature is 50.5 degrees Fahrenheit (°F); mean monthly temperatures range from 25°F in January to 75°F in July. Winds average about 5 knots and are generally out of the south and east-southeast, although winds from the north and northwest are common.

2.1.2 Overview of Geology and Hydrogeology

2.1.2.1 Regional Geology and Hydrogeology

The geologic formations exposed at the surface in the vicinity of Hill AFB vary from Precambrian-age crystalline bedrock at the western margin of the Wasatch Mountain Range to Pleistocene unconsolidated deposits forming benches, plateaus, and lowlands west of the Wasatch Front (Figures 2.1 and 2.1a). Hill AFB is situated on a plateau that is an erosional remnant of a fan-delta complex formed when sediments were transported from the Wasatch front into Pleistocene Lake Bonneville. Primarily, coarse-grained fan-delta deposits of the most recent Provo stage of Lake Bonneville are exposed within the boundaries of the Base. The fan-delta has been dissected along the northeastern

Symbol	System	Series	Formation and Lithology	Thickness in Feet		
Qa Qg Qs Qc	Quaternary	Recent	Alluvium: Permeable river sand and gravel; includes mudflow deposits near mountains which are impermeable locally. Gravel: Permeable floodplain sand and gravel. Sand: Permeable fine sands underlying low-lands. Clay: Impermeable plastic to non-plastic clay overlaying artesian aquifer.	200 10-20 35+		
UNCONFORMITY						
Qpg Qpgs Qps			Quaternary	Pleistocene	(Lake Bonneville Group): Provo Formation: gravel, permeable; gravel and sand, permeable; sand, permeable	5-20 10-50 10-20
Qba					Bonneville and Alpine Formation: sand and gravel over bedrock, very permeable	5-50
Qag Qas Qac	Alpine Formation: gravel, permeable; sand, permeable; clay silt, fine sand, usually impermeable;	<25 100 200				
Q	Unconsolidated basin-fill deposits	>1000				
UNCONFORMITY						
Ca	Cambrian	Middle to Late (?)	Limestone: Silty with interbedded shale and dolomite. Permeable.	1375(±)		
Cl		Lower to Middle (?)	Tintic Quartzite: massive, cross-bedded, pebbly. Permeable where fractured.	500-700		
ANGULAR UNCONFORMITY						
Pcf		Precambrian	Farmington Canyon Complex: metasedimentary and metavolcanic rocks. Permeable where jointed or fractured.	10,000		

SOURCE: Modified from Feth et al. (1966)

FIGURE 2.1

GENERALIZED STRATIGRAPHY OF THE HILL AFB AREA

Hill Air Force Base, Utah

**PARSONS
ENGINEERING SCIENCE, INC.**

Source: Radian, 1995.

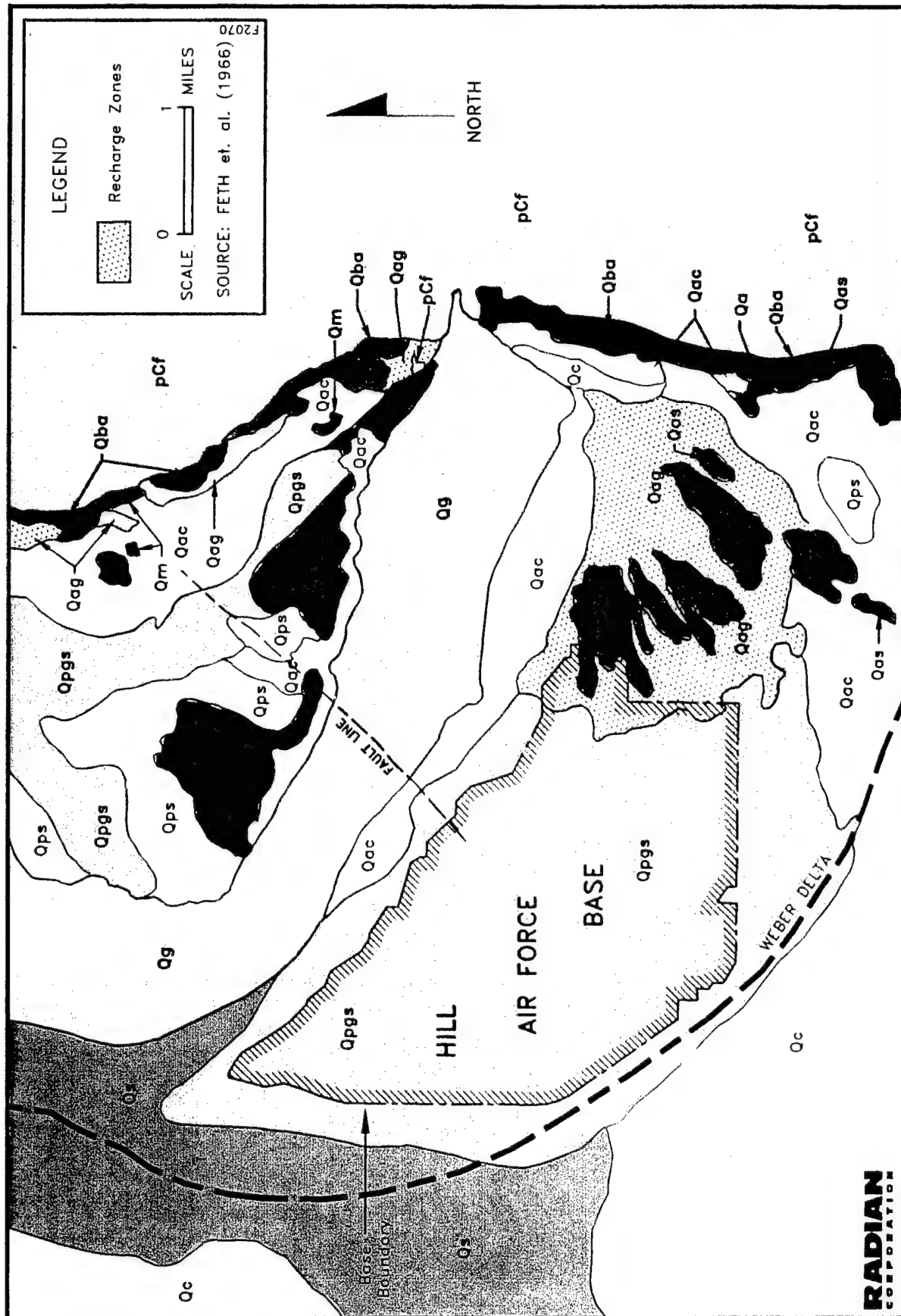


Figure 2.1a Hill AFB Surface Geology (See Figure 2.1 for Description of Map Symbols)

perimeter of the Base by the Weber River, creating a steep terrace. Older Alpine stage sediments of Lake Bonneville generally underlie the Provo deposits, and the silts, sands, and clays of a lower Alpine unit (Qac) are exposed on the steep hillsides northeast of the Base. Although older than the Provo stage sediments, some of the upper Alpine stage units were deposited at higher altitudes than Provo stage sediments because the lake level was higher during Alpine time. These upper coarse-grained Alpine units (Qag and Qas) crop out at the far eastern portion of the Base and form remnant hilltops.

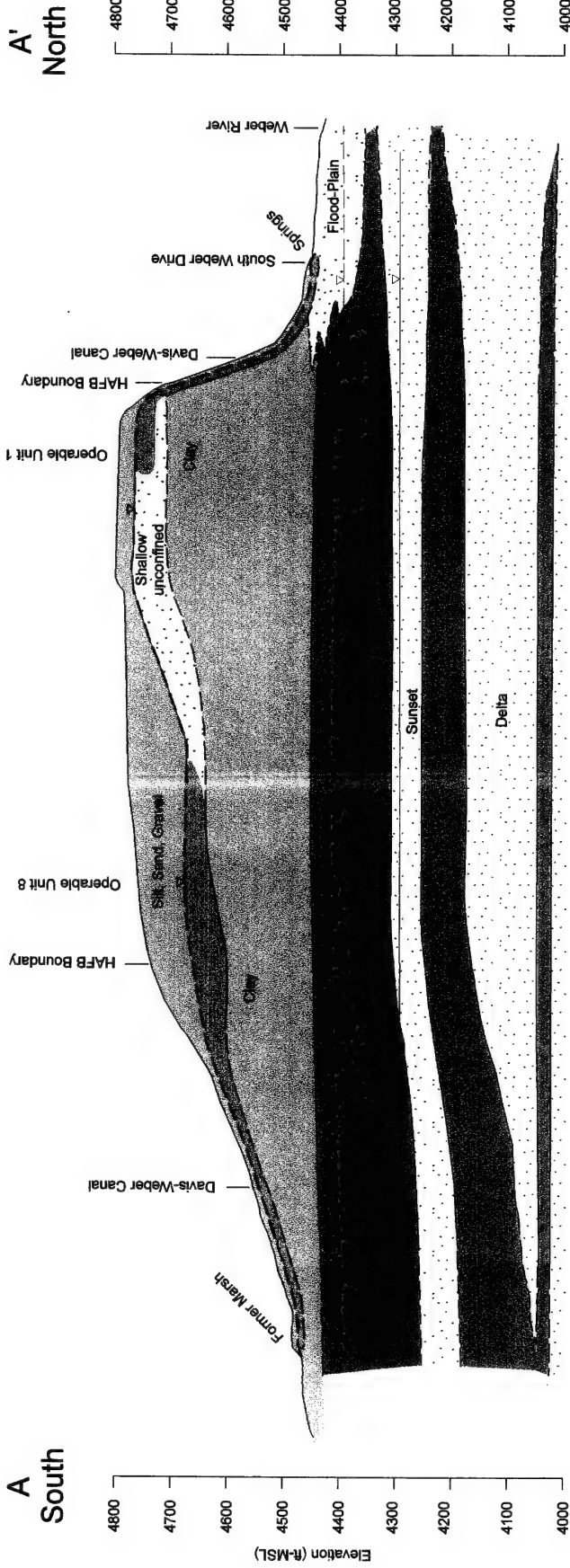
Perched, shallow, water-bearing zones that collectively form a shallow unconfined aquifer system are present in the unconsolidated Provo and Alpine stage Lake Bonneville deposits. Groundwater flow in the shallow groundwater system is to the north-northeast in the OU 2 area. Elsewhere on the Base, groundwater flow in the shallow groundwater system varies, and the flow direction and magnitude may be locally controlled by topography or subsurface features.

In addition to the formations exposed at the surface, 2,000 to 3,000 feet of pre-Lake Bonneville sediments are present in a north- to south-trending graben underlying the area of Hill AFB (Feth *et al.*, 1966). This basin fill consists of thick sequences of interbedded coarse alluvium and lacustrine clays. The coarse alluvial units are successively older (and deeper) lobes and layers of the fan-delta complex, and they function as artesian aquifers. Two artesian aquifers supply water to Hill AFB and the surrounding communities: the low-transmissivity Sunset Aquifer and the deeper, highly transmissive Delta Aquifer. The general pattern of groundwater flow in the deeper aquifers is east to west, from the recharge areas toward the Great Salt Lake. The potentiometric surfaces in the deep aquifers beneath the Base are relatively flat. However, because of high pumpage, local perturbations of the potentiometric surfaces are evident, and the potentiometric surfaces have been lowered substantially. Cross-sections showing the relationship of the hydrostratigraphic units beneath the base and the potentiometric surfaces of the aquifers have been developed by Parsons ES. The lines of cross-section are shown in Figure 2.2 and cross-sections in Figures 2.2 and 2.3. The hydrostratigraphic cross-sections have been constructed from the data obtained from published technical reports and Hill AFB RI results, and drillers' logs of deep production wells.

With respect to the regional groundwater flow net, vertical components of flow are downward in recharge areas near the mountain front and upward in discharge areas to the west of the Base near the Great Salt Lake. This general pattern of recharge and discharge may be affected locally by groundwater pumping, but should be relatively unaffected at the regional scale. Based on the potentiometric surfaces of the aquifers beneath the Base, downward components of flow from the shallow unconfined aquifer to the deeper Sunset and Delta aquifers are inferred. However, the downward movement of groundwater through the clay layers and confining units between the aquifers depends on the degree of

A
South

A'
North



Legend:



Aquifers (Shallow Unconfined, Flood-plain, Sunset, Delta)



Groundwater Contaminant Plumes



Lake Bonneville Group (Provo and Alpine Stage)



Confining Units (primarily clay)

--- -- Shallow Unconfined Aquifer static water level

--- -- Sunset Aquifer potentiometric surface (JMM, 1989)

--- -- Delta Aquifer potentiometric surface - 1985 (Clark and others, 1990)

--- -- Contact (dashed where inferred)

0 2000
Horizontal Scale in Feet
Vertical Exaggeration = 10x

FIGURE 2.3
HYDROSTRATIGRAPHIC
CROSS-SECTION A-A'

HILL AIR FORCE BASE, UTAH

PARSONS
ENGINEERING SCIENCE, INC.

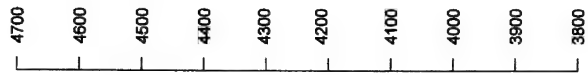
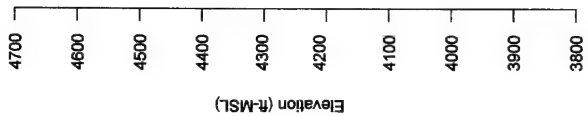
SALT LAKE CITY, UTAH

B
West

Operable Unit 5
HAFB Boundary
Davis-Weber Canal
L-15
Sunset City
Clay

Operable Unit 4
HAFB Boundary
Davis-Weber Canal
Seeps
South Weber Drive
L-80
Flood-Plain
Weber River

B'
East



Legend:



--- -- Shallow Unconfined Aquifer static water level

--- -- Sunset Aquifer potentiometric surface (JMM, 1988)

--- -- Delta Aquifer potentiometric surface - 1985 (Clark and others, 1980)

--- -- Contact (dashed where inferred)

Note: Upward hydraulic gradients are present in the Flood-plain Aquifer at OU4 (USGS, 1992)

FIGURE 2.4

HYDROSTRATIGRAPHIC
CROSS-SECTION B-B'

HILL AIR FORCE BASE, UTAH

PARSONS
ENGINEERING SCIENCE, INC.

SALT LAKE CITY, UTAH

hydraulic connection among the aquifers, which in turn depends on the thickness and hydraulic properties of the clay layers separating the aquifers. Drillers' logs indicate that the confining units in the area of the Base are primarily tight blue-gray clay. The extensive clays separating the aquifers appear to limit the hydraulic connection among the aquifers, and thus, the amount of recharge and vertical leakage. The deep aquifer system becomes unconfined and less differentiated near the mountain front and the mouth of Weber Canyon. This eastward unconfined extension of the deep aquifer system is the main source of recharge to the deep aquifers. Recharge to the deeper aquifers primarily occurs near the mountain front by direct infiltration into the more permeable Lake Bonneville deposits and by seepage losses from the Weber River. The aquifers are less differentiated near the valley areas adjacent to OU 1 and OU 2 [(see cross-section A-A' (Figure 2.3) and plume location map (Figure 2.2)]. The Sunset and Delta aquifers are better differentiated near OU 4, and the Weber River drainage is underlain by a thicker sequence of clay [see cross-section B-B' (Figure 2.4)]. Therefore, the river does not appear to be a primary source of groundwater influx to the deeper aquifers in the area of OU 4. Conversely, seepage gains in the river indicate upward leakage from the Sunset Aquifer in the valley areas adjacent to OU 4 (USGS, 1992).

High-yield production wells at Hill AFB are screened in one or both coarse-grained water-bearing units of the Delta Aquifer starting at about the 4,200 feet elevation. Logs for city wells to the west and south of Hill AFB indicate that the upper water-bearing unit or lobe of the Delta Aquifer fan complex thins and eventually terminates in these directions. Therefore, this upper lobe is unique to the Hill AFB area. The lower water-bearing unit of the Delta Aquifer is tapped elsewhere outside of the Base. The shallower, lower yield Sunset Aquifer is more differentiated from the Delta Aquifer in the areas west and southwest of the Base and is used for water supply in these areas, though less frequently than the Delta Aquifer.

The areal extent and morphology (derived from the RIs) of the dissolved CAH groundwater plumes at OUs 1, 2, 4, 5, 6, and 8 are shown in Figure 2.2. The relationships between the geology, topography, hydrostratigraphic units, and selected dissolved CAH plumes beneath Hill AFB are shown on hydrostratigraphic cross-sections A-A' and B-B' (Figures 2.3 and 2.4). As shown in the figures, the plume morphologies and extents are geologically, topographically, and hydrologically controlled, and they all terminate at approximately the same elevation (4,440 to 4,450 feet msl). In the upper part of the fan-delta, the interaction of Lake Bonneville and the delta resulted in a complex system of interfingering lenticular strata where the more coarse-grained units likely act as preferential pathways for contaminant transport. For instance, the groundwater plume at OU 6 is constrained to a long, narrow trough of coarser sediment bounded on all sides by less permeable fine-grained sediments (Figure 2.2). Conversely, the plume at OU 5 is less constrained laterally and is thus wider. All plumes are constrained vertically with

depth by the progressively more fine-grained units within the Lake Bonneville Group deposits, with the base of the shallow groundwater system (shallow unconfined aquifer) defined by an irregular contact surface with low-permeability clay (Figures 2.3 and 2.4).

As noted, relatively coarse-grained units may control plume migration in areas with complex and variable stratigraphy. Contaminants likely flow through zones with higher hydraulic conductivities relative to surrounding sediments. Given that the shallow groundwater system beneath Hill AFB consists of highly heterogeneous alluvial sediments deposited in a fan-delta complex, the potential for preferential and rapid migration in coarse-grained units must be considered when evaluating groundwater contaminant migration. For example, at OU 5, groundwater velocity measurements have been collected using a borehole flowmeter (Wheeler, 1996). These data suggest that within a single well, velocities may vary by a factor as great as 10, and that across the site, velocities may differ by a factor of nearly 70 (i.e., nearly two orders of magnitude). This has also been observed at UST Site 870 at Hill AFB (JMM, 1993; Parsons ES, 1995). At that site, slug and pumping tests were conducted in wells screened across different stratigraphic intervals (e.g., some fine grained and some coarse). Results of these tests varied over two orders of magnitude, suggesting that for equivalent gradients and porosities, groundwater velocities at Site 870 could vary by two orders of magnitude. In general, at Site 870, wells with higher measured hydraulic conductivities were screened mostly across sandy intervals, while wells with lower measured conductivities were screened mostly across finer-grained intervals (containing more silt and clay). Due to this heterogeneity, use of an average hydraulic conductivity for transport modeling may not be appropriate.

Contaminants at the OUs have migrated vertically through the coarse, near-surface sediments to the shallow perched water table and have then migrated laterally off-base. The plumes terminate in the vicinity of springs, seeps, or marshy areas. Discharge also occurs at other upslope spring/seep locations at most of the OUs. The spring/seep line of discharge at the downgradient leading edges of the plumes may result from several factors such as structural contacts with clay units, topographic low spots, and upward hydraulic gradients in the lowland areas. Upward hydraulic gradients were confirmed in the Weber River flood-plain silts, sands, and gravels at the downgradient reaches of the OU 4 plume (USGS, 1992), as shown on Figure 2.4. Upward hydraulic gradients in shallow groundwater also may be present at the other OUs, and this as well as other factors (e.g., discharge, evapotranspiration, dilution, dispersion, biodegradation, etc.) appear to be controlling the downgradient extent of the plumes, and may be the reason that the plumes all terminate at approximately the same elevation (see Figure 2.2).

Natural attenuation mechanisms appear to have stabilized the leading edge of the plumes at their current location and elevation. This conclusion is supported by chemical

data obtained from the off-base downgradient springs and seeps. Since 1986, many of the springs and seeps at the downgradient edges of the plumes have been sampled and analyzed for CAHs, with no apparent increasing trend. For example, the spring below Petersons Pond at OU 2 contained TCE at a concentration of 44 micrograms per liter (ug/L) when first sampled in 1986. A maximum TCE concentration of 373 ug/L was detected in May 1987, and concentrations of TCE have diminished since 1987. Seasonal variability may be more significant than long-term trends because concentrations of CAHs in this spring and downgradient springs at the other OUs are generally higher in the late spring and summer months. At OU 8, off-base downgradient field drains have contained CAHs since they were first sampled in the 1980s. During the period from 1986 to 1994, concentrations of TCE ranging from 16 ug/L to 89 ug/L, with no apparent increase, have been detected in a field drain behind the Jay Harris residence, which is located south of the Davis-Weber Canal. Approximately 1,500 feet further downgradient, TCE was detected at concentrations ranging from 11 ug/L to 21 ug/L in water collected from a manhole at the Reed Robins residence. These analytical data are for 1987 only. This location corresponds to the furthest downgradient detection of CAHs at OU 8. A marshy area is located just south of this sampling location and appears to be a point of shallow groundwater discharge (Figure 2.3). However, most of this area recently has been developed, potentially modifying the hydrologic regime. At OU 5, relatively low concentrations of TCE were detected in two shallow domestic wells near 700 West in Sunset as early as 1987. Fred Chicado's well contained TCE at a concentration of 3.4 ug/L in 1987. TCE concentrations ranging from 6.6 ug/L to 7.5 ug/L were detected in Omer's well between 1989 and 1990. Martin Spring has contained concentrations of TCE ranging from 4.4 ug/L to 5.8 ug/L between 1989 and 1990, and a maximum 1,2-DCE concentration of 8.9 ug/L also was detected. The presence of relatively stable concentrations of CAHs in spring water, field drains, and shallow groundwater water far downgradient of the source areas, as early as 1986, implies that the plumes are stable and are no longer increasing in size.

2.1.2.2 OU 2 Geology and Hydrogeology

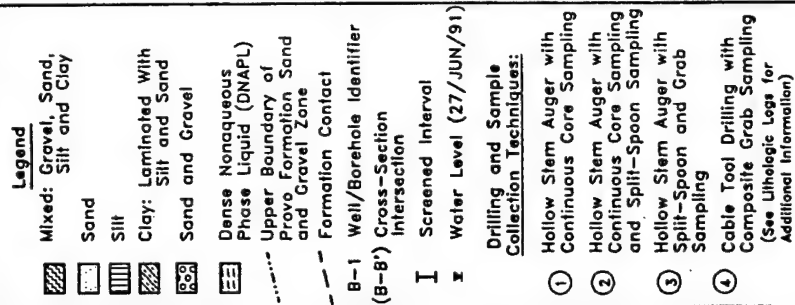
The hydrogeologic features of the shallow groundwater system in the vicinity of OU 2, and shallow subsurface stratigraphy, have been characterized from the subsurface investigations previously cited. The geologic features near the OU 2 source area and hydraulically downgradient, off-base areas are defined by a combination of drilling and continuous logging of soil boring and monitoring well locations, geophysical surveys, and cone penetrometer testing (CPT). The occurrence and flow of groundwater have been defined from the collection of water-level measurements in monitoring wells and CPT locations, and aquifer pump tests near the source area.

The shallow subsurface features at OU 2 are consistent with the regional setting of the Lake Bonneville Provo and Alpine stage deposits. A north to south hydrogeological cross-section through the on-base source area is provided in Figure 2.5 (the line of section is not provided). This 500-foot section shows that 15 to 40 feet of upper fine-to coarse-grained sediment forms an irregular contact with a basal clay. The surface of the basal clay forms a north-south trending trough beneath the disposal trenches where structural lows have allowed for the accumulation of DNAPL. As shown on the cross-section, DNAPL has migrated to depths of about 60 feet below ground surface (bgs), approximately 30 to 40 feet below the water table. Depressions in the basal clay tend to have limited the lateral migration of DNAPL from the source area (Radian, 1994). The basal clay is at a structurally higher elevation to the east and downslope of the trenches (Radian, 1994). A generalized cross-section along the downgradient flowpath from the disposal pit to the Weber River Valley is shown in Figure 2.6, and portrays the relationship of the DNAPL source to the geology, topography, and hydrology of the slope throughout the OU 2 study area. The line of section is shown in Figure 1.2.

The subsurface stratigraphy in the downslope and hydraulically downgradient areas east of the Davis-Weber Canal is portrayed in selected hydrogeologic cross-sections (Figures 2.7, 2.8 and 2.9). The lines of cross-section are provided in Figure 2.10. The localized nature of the shallow groundwater system is evident from the cross-sections. The deposits are primarily fine-grained silts and clays with interbedded coarser-grained sands and gravels that vary laterally and with depth, but become progressively more fine grained with depth. The subsurface stratigraphy has been modified substantially by slumping in the area of these cross-sections (Radian, 1994). This slumping combined with the complex depositional environment has created a heterogeneous subsurface that makes geological correlation difficult. The knolls shown on the cross-sections are thought to be the toe of a rotational slump (Radian, 1994). The primarily fine-grained sediments comprising the knolls appear to form a hydrogeologic barrier to shallow groundwater flow (Radian, 1994). Groundwater, where encountered near the knolls, is encountered at greater depths, and this greater depth of groundwater and lack of organic contaminants suggests that the deeper groundwater beneath the knolls and the hillside east and downslope of the knolls has little hydrogeologic continuity with the shallow zone (Radian, 1994).

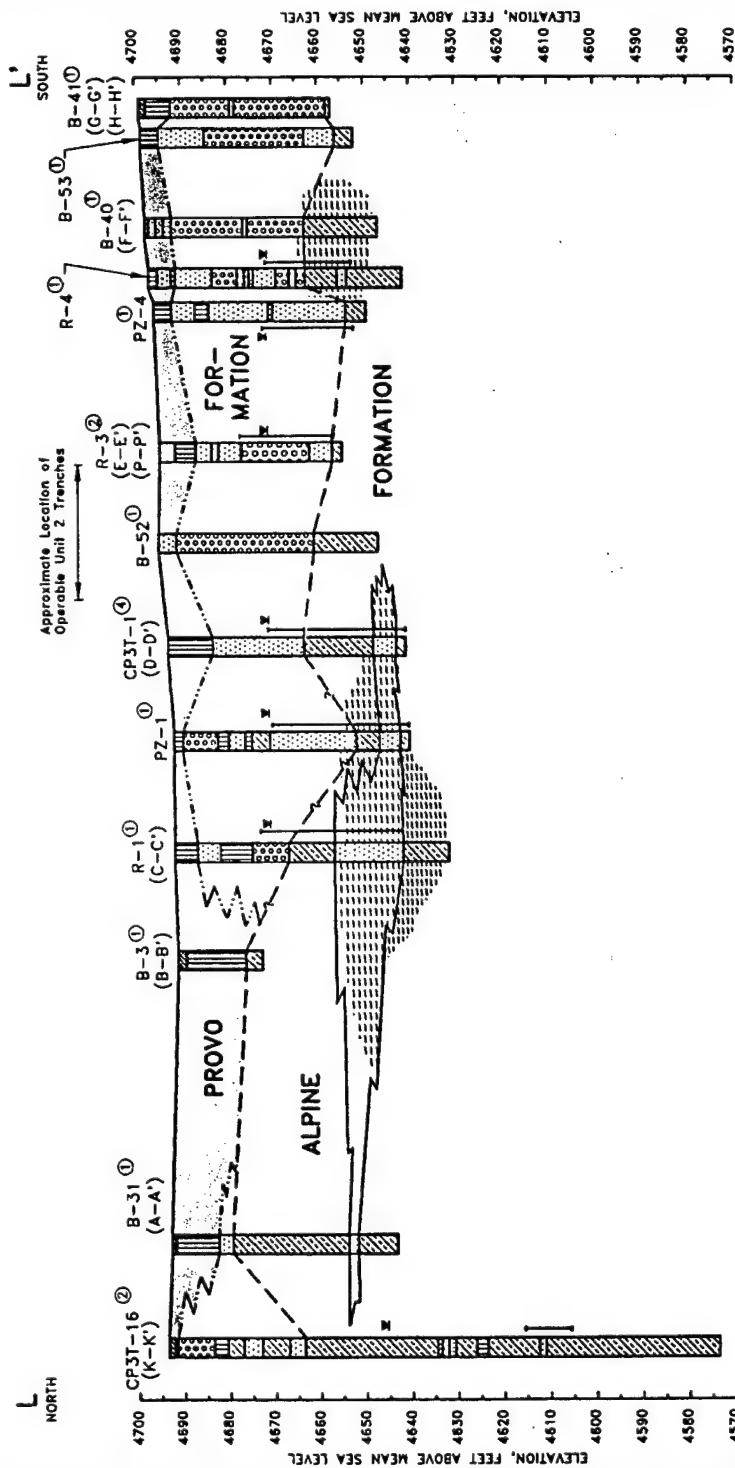
The static groundwater elevation in the vicinity of OU 2 is locally variable, depending on the surface topography and subsurface geology. The depth to groundwater in the shallow groundwater system in the off-base area is illustrated in Figure 2.11. A map of the potentiometric surface for this same area is provided in Figure 2.12 (the dates of

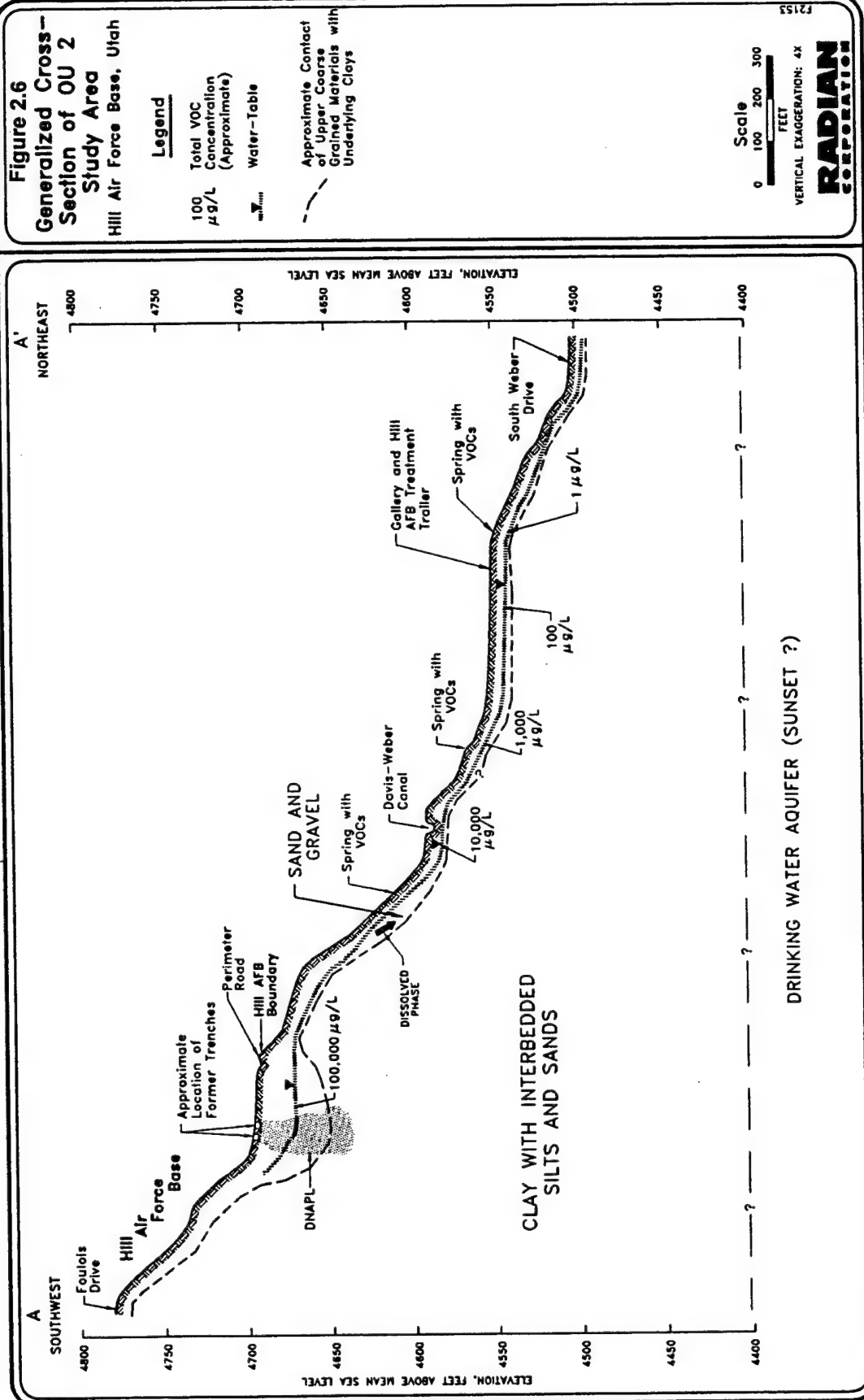
Figure 2.5
Hydrogeological
Cross-Section L-L'
 Operable Unit 2
 Hill Air Force Base, Utah



VERTICAL EXAGGERATION: 2X

RADIAN
 CORPORATION





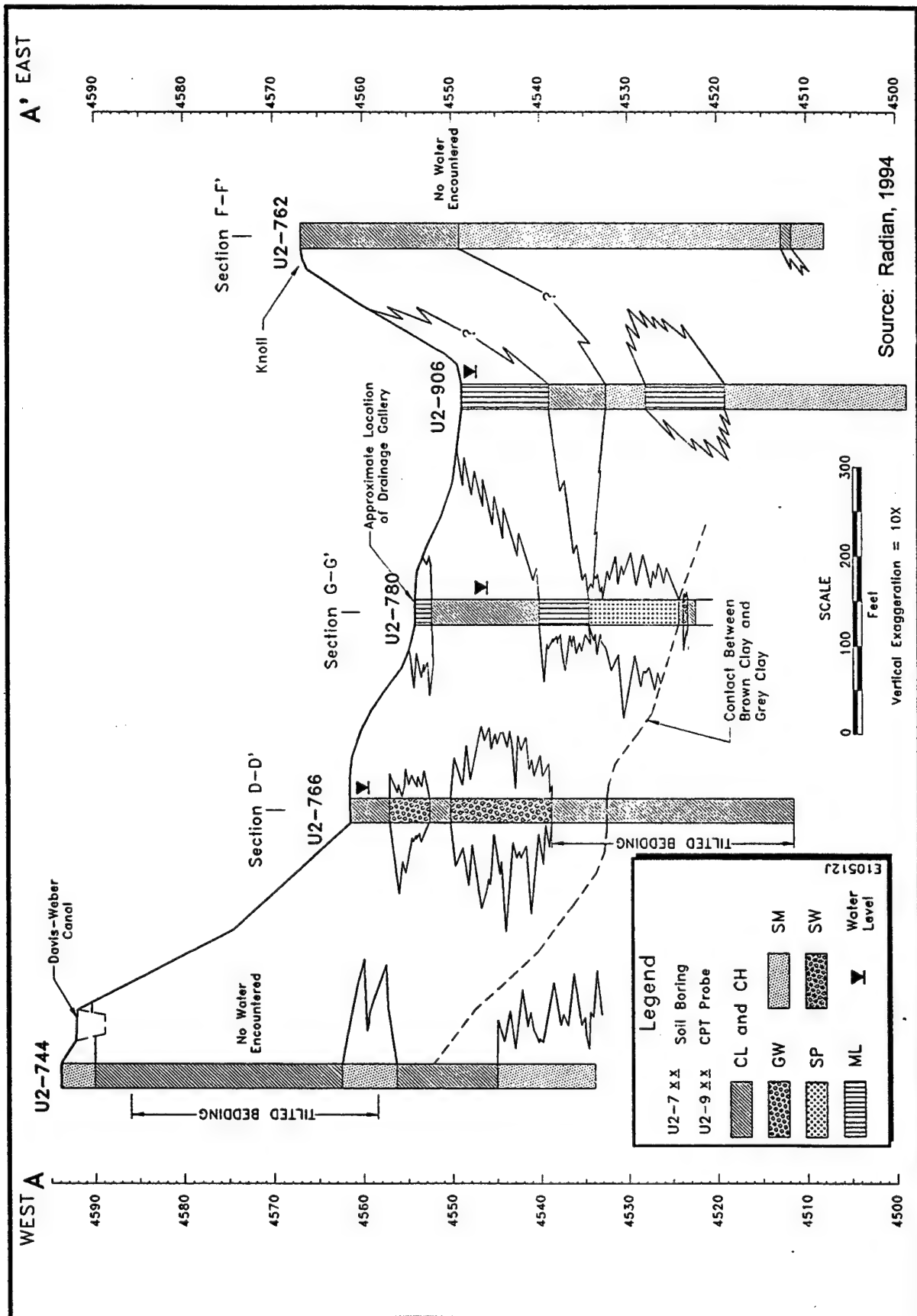


Figure 2.7 Hydrogeologic Cross-Section A-A'

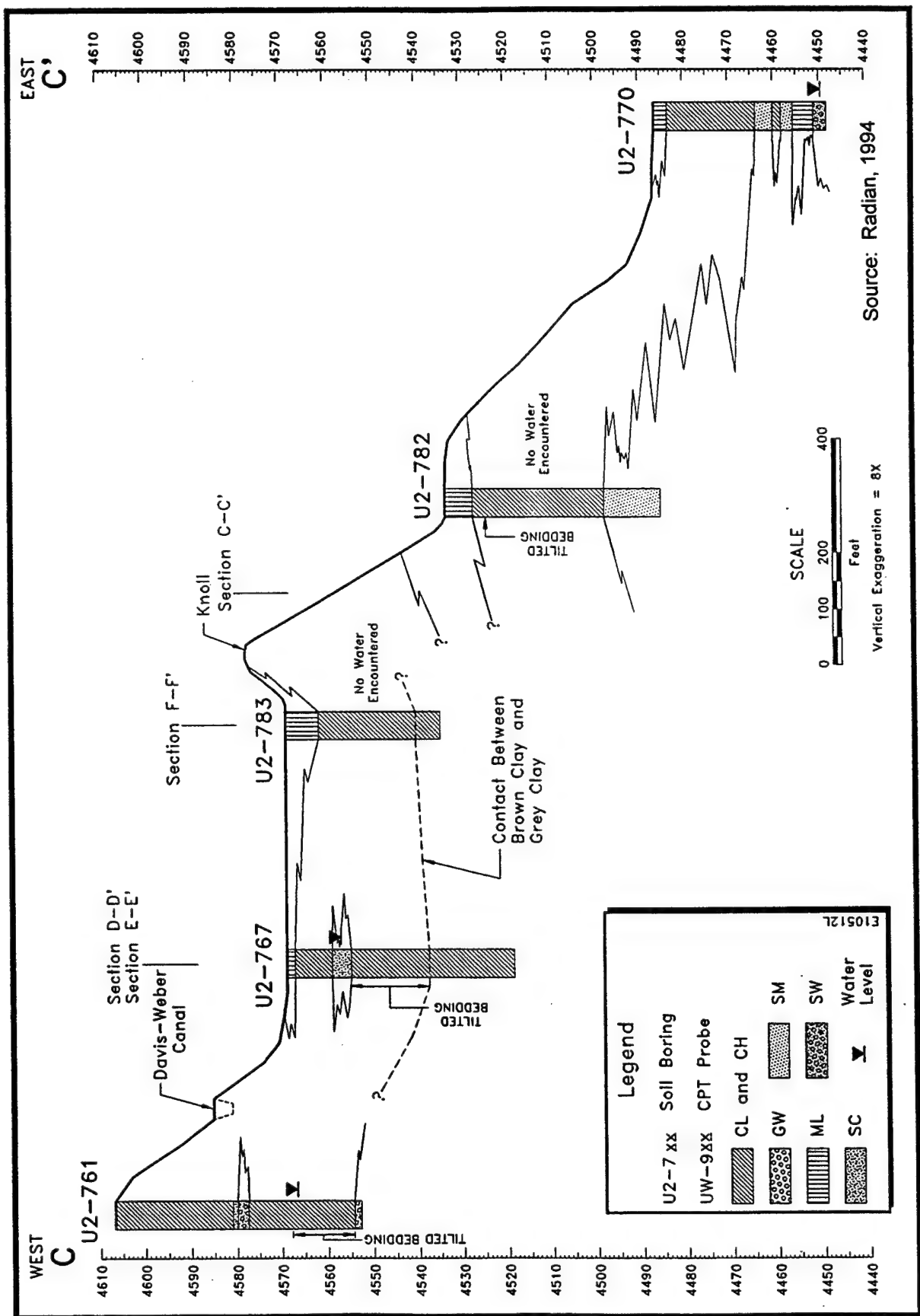


Figure 2.8 Hydrogeologic Cross-Section C-C'

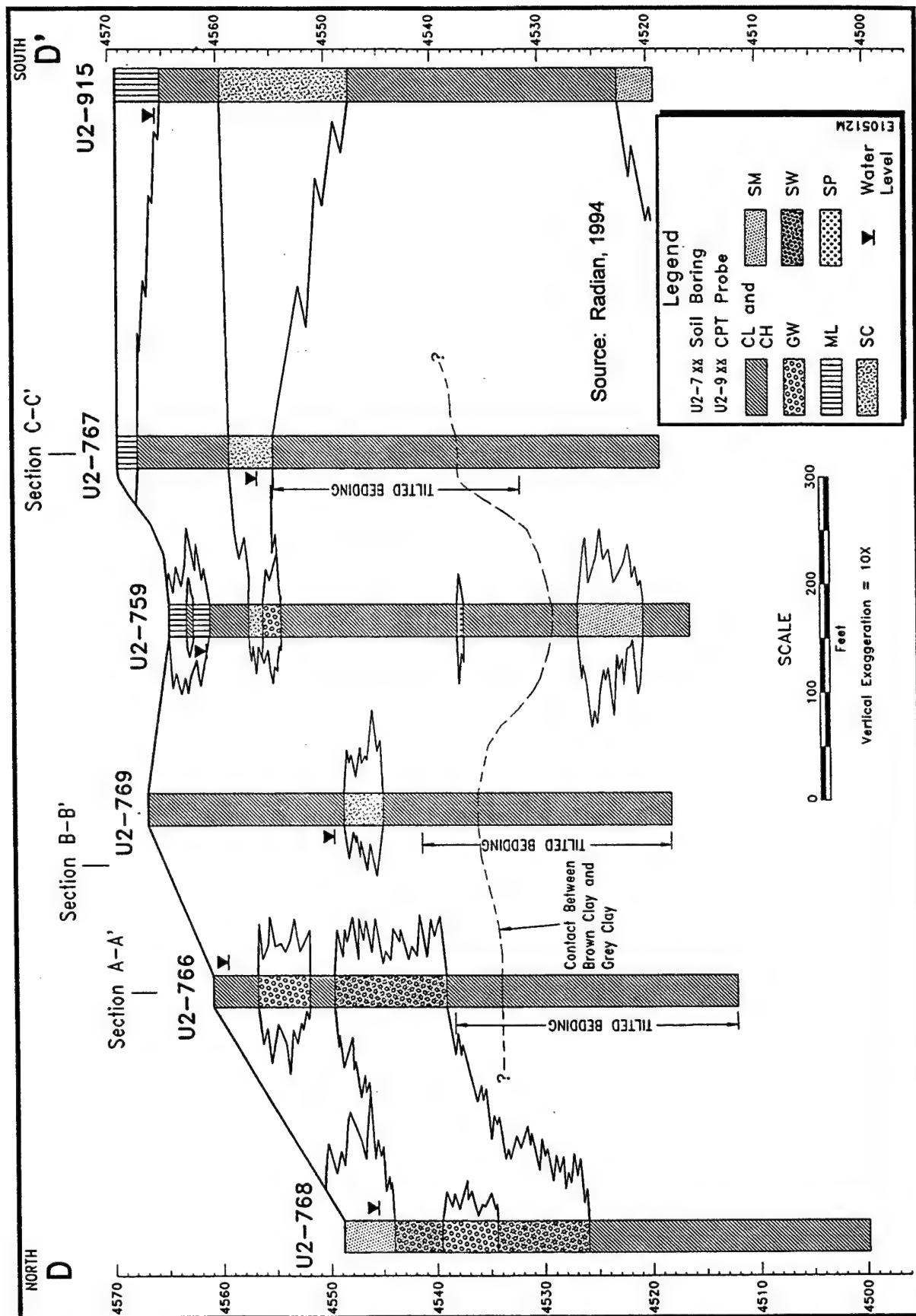
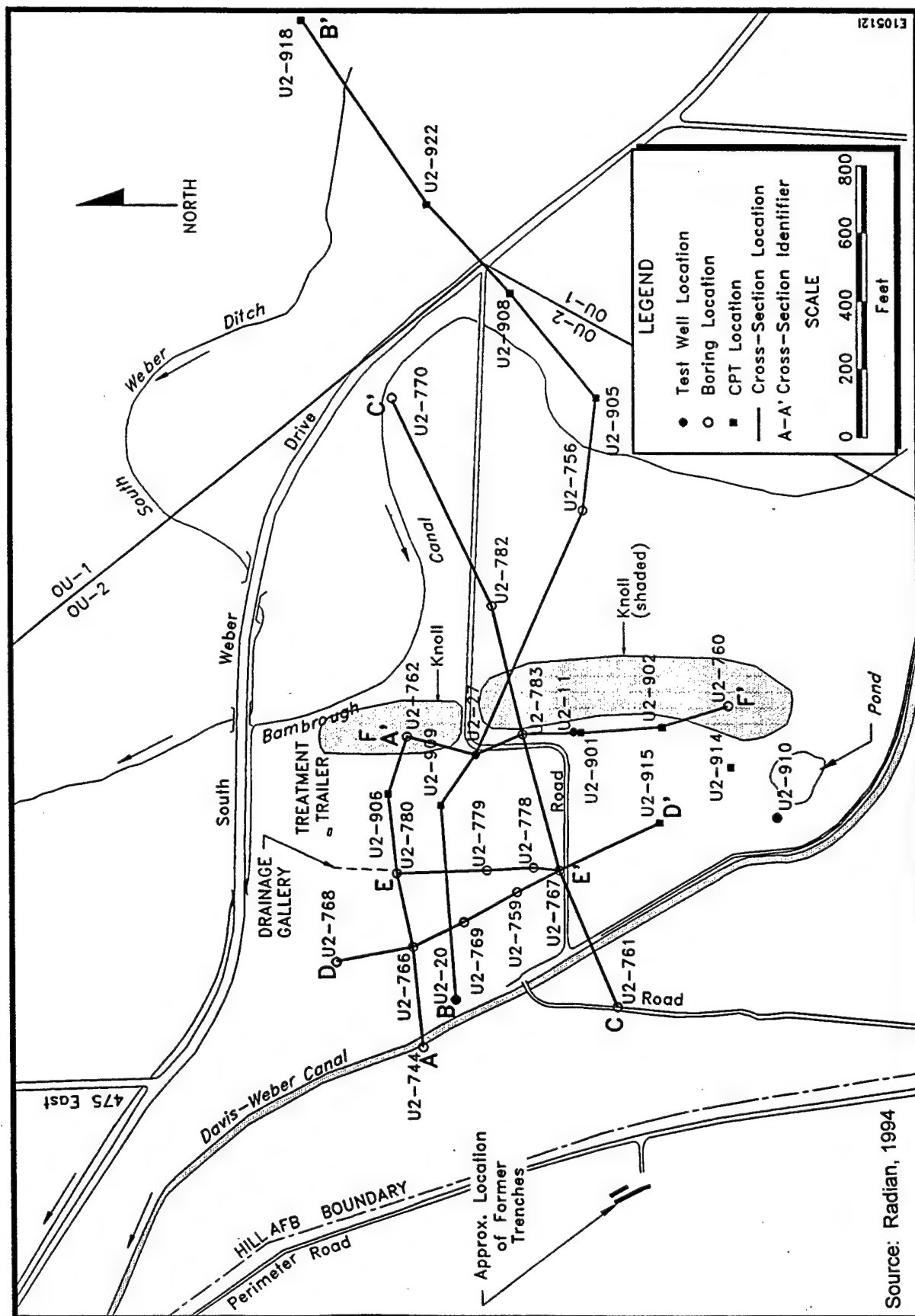


Figure 2.9 Hydrogeologic Cross-Section D-D'



Source: Radian, 1994

Figure 2.10 Location of Hydrogeologic Cross-Sections

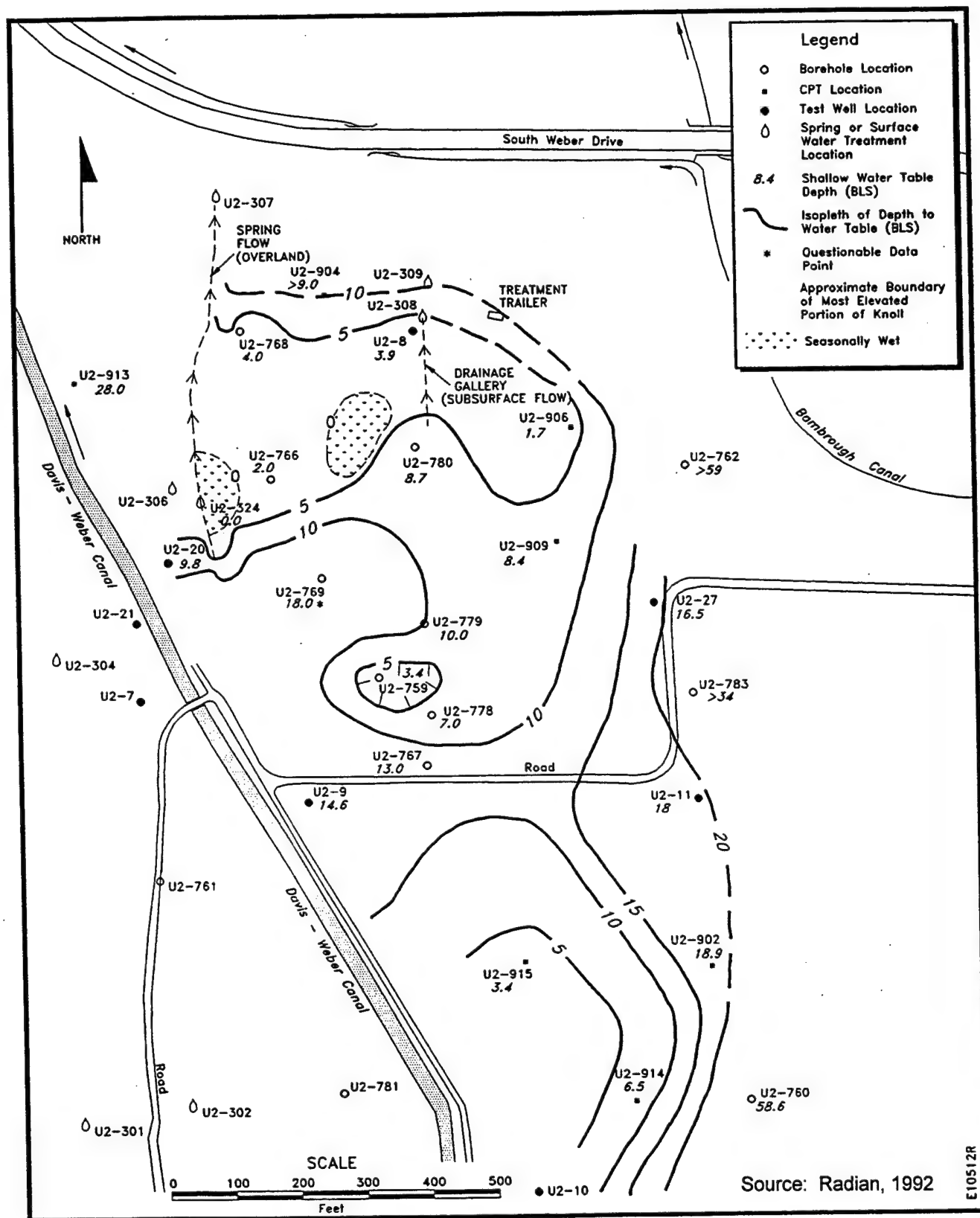


Figure 2.11 Depth to Groundwater in the Off-Base Shallow Groundwater System

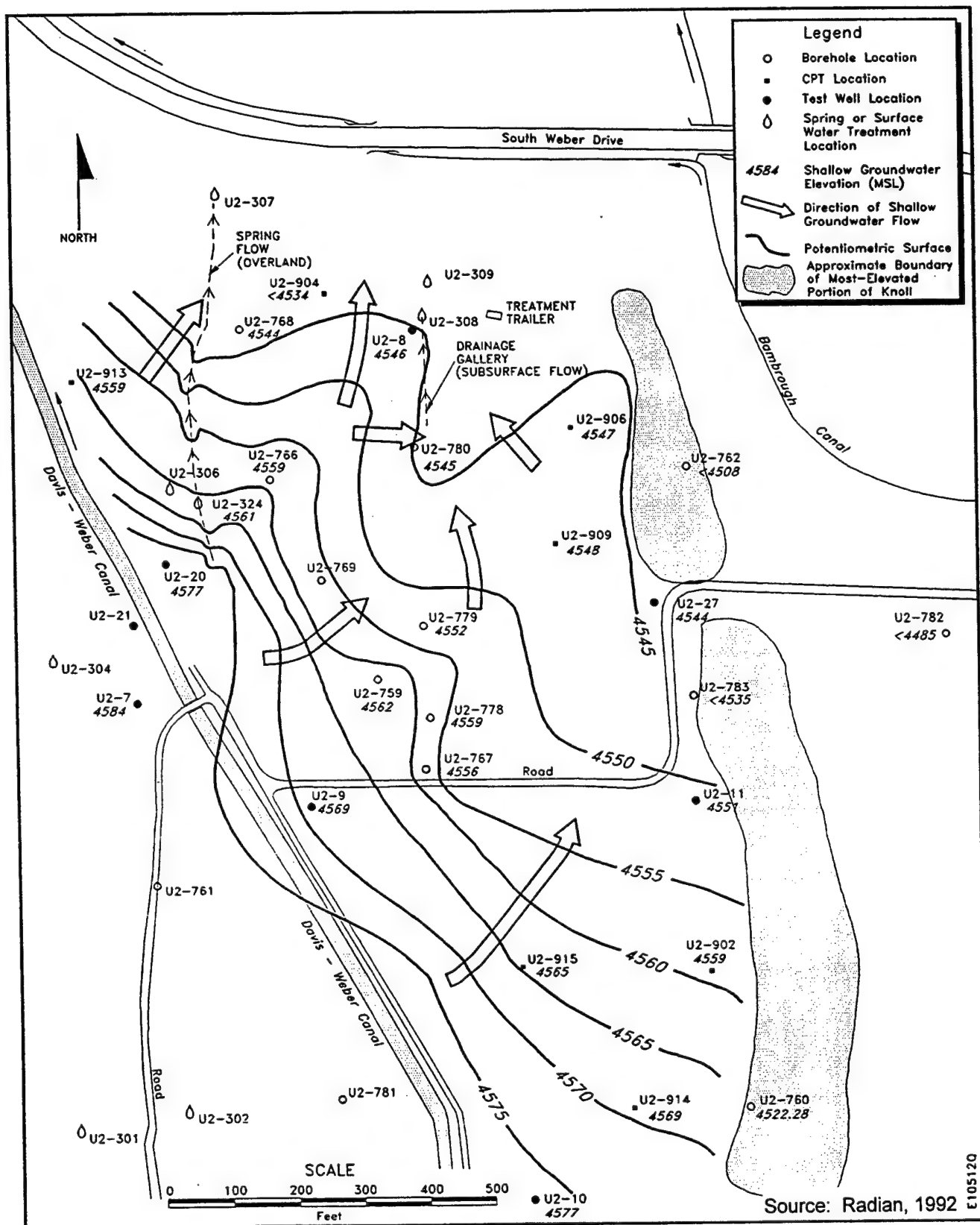


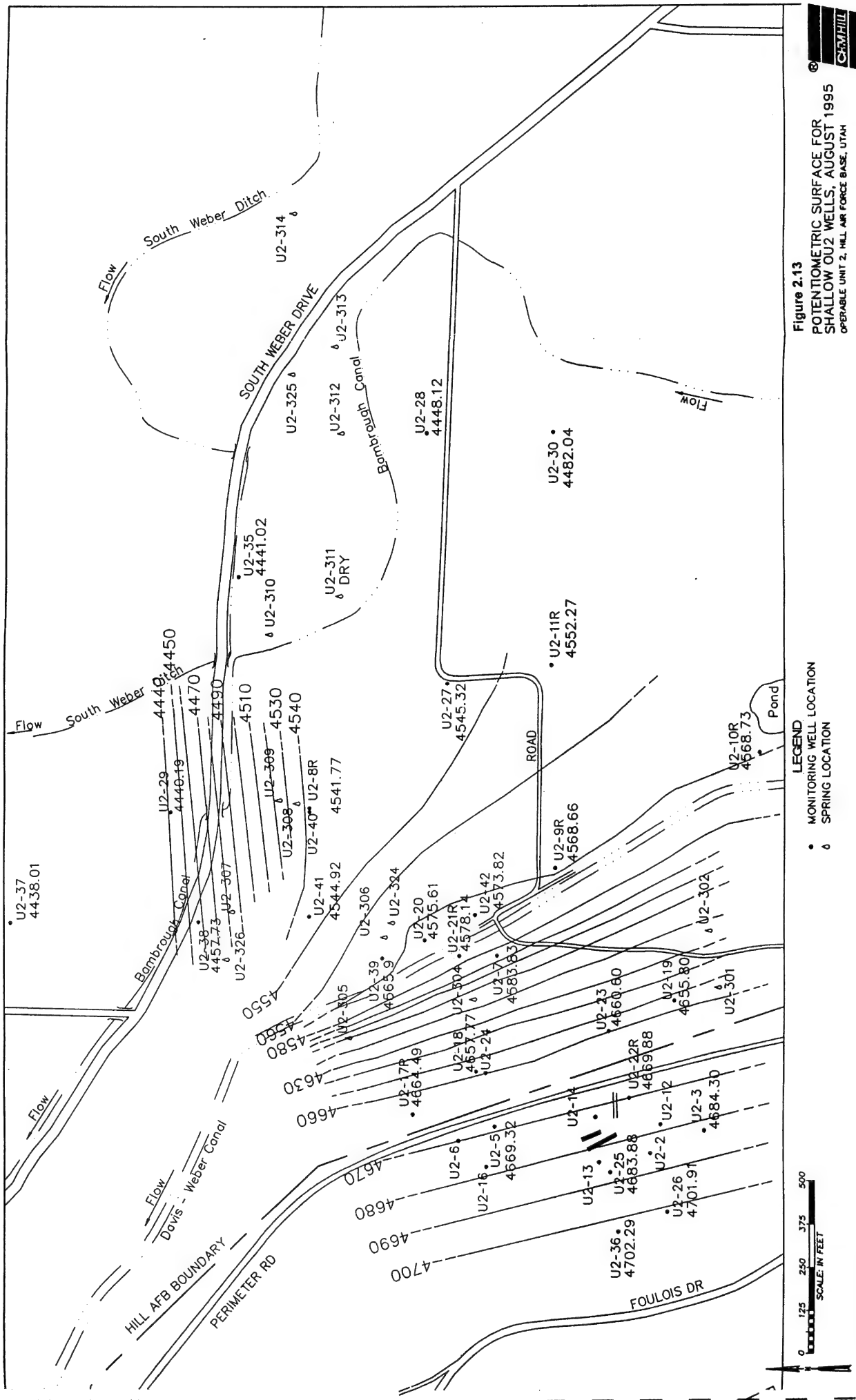
Figure 2.12 Potentiometric Surface of the Off-Base Shallow Groundwater System

groundwater measurement were not given by the authors). Groundwater is very shallow in the areas east and north of Davis-Weber Canal, and intersects the surface at some lower elevation areas, forming seasonally wet areas. Continued monitoring of groundwater levels since the RIs indicate seasonal fluctuations occur (CH₂M Hill, 1996). Water levels are typically higher during spring recharge, which lasts from April to August (CH₂M Hill, 1996).

The groundwater potentiometric surface, flow direction, and hydraulic gradient for the latest August 1995 and February 1996 sampling rounds are shown in Figures 2.13 and 2.14 (CH₂M Hill, 1996). As shown on the potentiometric surface maps and hydrogeological cross-sections, shallow groundwater flow at OU 2 is topographically and geologically controlled and is primarily constrained to the near surface. The groundwater elevation data indicate that shallow groundwater flows east-northeast along the hillside from the OU 2 source areas to the Davis-Weber Canal. East of the canal shallow groundwater flows more northerly, and is almost due north where springs U2-307 and U2-308 emerge from the hillside. The more northerly flow direction in the further downgradient areas appears to be primarily controlled by the subsurface geology [i.e., the structural isopach surface of the basal fine-grained units and the hydrogeologic barrier beneath the knolls (CH₂M Hill, 1996)]. Although the hydraulic gradient changes seasonally and with wet and dry precipitation cycles, the general pattern of groundwater flow (direction) is consistent with time. Much of the shallow groundwater appears to discharge from seeps and springs located along the hillside, north of Davis-Weber Canal and south of South Weber Drive.

As shown in Figures 2.13 and 2.14, the hydraulic gradient steepens between perimeter road and Davis-Weber Canal, flattens east of the canal, then steepens again on the hillside slope above South Weber Drive. The gradient is approximately 0.2 ft/ft between perimeter road and the canal. The gradient flattens to about 0.06 ft/ft in the area between the canal and the knolls, and then increases to about 0.25 ft/ft to the north of spring U2-308 until flattening again in the Weber River Valley.

Apparently, the hydraulic properties of the shallow groundwater system at OU 2 have only been defined at the Chemical Pit 3 source area. Constant discharge pumping tests were performed in 1988 in wells screened in coarse sediments near the DNAPL sources. The hydraulic conductivity of the sands ranged from 10 to 40 ft/day (Radian, 1992). While these values indicate the potential for migration near the source areas, they may not be a good estimate for the aquifer properties in the shallow groundwater system of the steep hillside hydraulically downgradient of the source areas. The mean hydraulic conductivity of the shallow, hillside groundwater system at OU 4 was about 1 ft/day, and decreased with depth (USGS, 1992). The shallow, hillside system at OU 2 is similar to OU 4, so the results at OU 4 could be generally applied to OU 2. Regardless of the



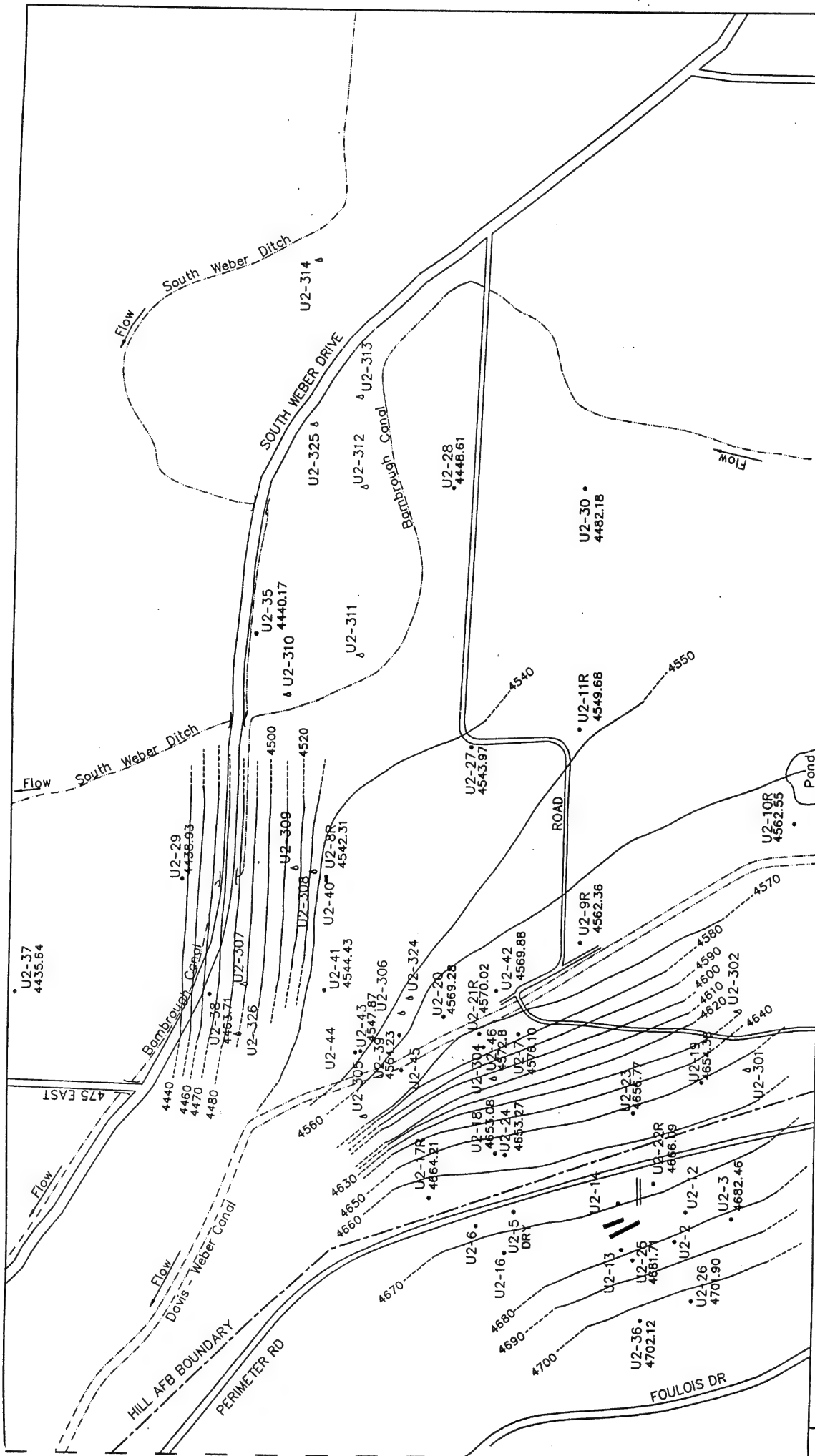


Figure 2.14

POTENTIOMETRIC SURFACE FOR
SHALLOW U2 WELLS, FEB 96
OPERABLE UNIT 2, HILL AIR FORCE BASE, UTAH

LEGEND
• MONITORING WELL LOCATION
○ SPRING LOCATION



70134-1, FIGURES 2.14-2.15, 2.16-2.17, 2.18-2.19, 2.20-2.21, 2.22-2.23, 2.24-2.25, 2.26-2.27, 2.28-2.29, 2.30-2.31, 2.32-2.33, 2.34-2.35, 2.36-2.37, 2.38-2.39, 2.40-2.41, 2.42-2.43, 2.44-2.45, 2.46-2.47, 2.48-2.49, 2.50-2.51, 2.52-2.53, 2.54-2.55, 2.56-2.57, 2.58-2.59, 2.60-2.61, 2.62-2.63, 2.64-2.65, 2.66-2.67, 2.68-2.69, 2.70-2.71, 2.72-2.73, 2.74-2.75, 2.76-2.77, 2.78-2.79, 2.80-2.81, 2.82-2.83, 2.84-2.85, 2.86-2.87, 2.88-2.89, 2.90-2.91, 2.92-2.93, 2.94-2.95, 2.96-2.97, 2.98-2.99, 3.00-3.01, 3.02-3.03, 3.04-3.05, 3.06-3.07, 3.08-3.09, 3.10-3.11, 3.12-3.13, 3.14-3.15, 3.16-3.17, 3.18-3.19, 3.20-3.21, 3.22-3.23, 3.24-3.25, 3.26-3.27, 3.28-3.29, 3.30-3.31, 3.32-3.33, 3.34-3.35, 3.36-3.37, 3.38-3.39, 3.40-3.41, 3.42-3.43, 3.44-3.45, 3.46-3.47, 3.48-3.49, 3.50-3.51, 3.52-3.53, 3.54-3.55, 3.56-3.57, 3.58-3.59, 3.60-3.61, 3.62-3.63, 3.64-3.65, 3.66-3.67, 3.68-3.69, 3.70-3.71, 3.72-3.73, 3.74-3.75, 3.76-3.77, 3.78-3.79, 3.80-3.81, 3.82-3.83, 3.84-3.85, 3.86-3.87, 3.88-3.89, 3.90-3.91, 3.92-3.93, 3.94-3.95, 3.96-3.97, 3.98-3.99, 4.00-4.01, 4.02-4.03, 4.04-4.05, 4.06-4.07, 4.08-4.09, 4.10-4.11, 4.12-4.13, 4.14-4.15, 4.16-4.17, 4.18-4.19, 4.20-4.21, 4.22-4.23, 4.24-4.25, 4.26-4.27, 4.28-4.29, 4.30-4.31, 4.32-4.33, 4.34-4.35, 4.36-4.37, 4.38-4.39, 4.40-4.41, 4.42-4.43, 4.44-4.45, 4.46-4.47, 4.48-4.49, 4.50-4.51, 4.52-4.53, 4.54-4.55, 4.56-4.57, 4.58-4.59, 4.60-4.61, 4.62-4.63, 4.64-4.65, 4.66-4.67, 4.68-4.69, 4.70-4.71, 4.72-4.73, 4.74-4.75, 4.76-4.77, 4.78-4.79, 4.80-4.81, 4.82-4.83, 4.84-4.85, 4.86-4.87, 4.88-4.89, 4.90-4.91, 4.92-4.93, 4.94-4.95, 4.96-4.97, 4.98-4.99, 5.00-5.01, 5.02-5.03, 5.04-5.05, 5.06-5.07, 5.08-5.09, 5.10-5.11, 5.12-5.13, 5.14-5.15, 5.16-5.17, 5.18-5.19, 5.20-5.21, 5.22-5.23, 5.24-5.25, 5.26-5.27, 5.28-5.29, 5.30-5.31, 5.32-5.33, 5.34-5.35, 5.36-5.37, 5.38-5.39, 5.40-5.41, 5.42-5.43, 5.44-5.45, 5.46-5.47, 5.48-5.49, 5.50-5.51, 5.52-5.53, 5.54-5.55, 5.56-5.57, 5.58-5.59, 5.60-5.61, 5.62-5.63, 5.64-5.65, 5.66-5.67, 5.68-5.69, 5.70-5.71, 5.72-5.73, 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average hydraulic conductivity of the shallow groundwater system off-base, fast flow layers or channels probably are present due to the complex depositional environment and subsequent slump deformation. Therefore, hydraulic conductivities may vary by orders of magnitude among the subunits of the shallow groundwater system, and hence, groundwater velocities also may vary significantly. As part of an RNA evaluation, downhole flowmeters could be used to further define these parameters.

It appears that the subsurface geologic units are anisotropic and that shallow groundwater (and dissolved contaminants) preferentially move laterally rather than vertically (Radian, 1994). This interpretation is supported by data on the vertical distribution of TCE at some of the CPT/hydropunch locations, which shows TCE concentrations diminishing with depth (Radian, 1994). Limited geotechnical data also indicate relatively low values of vertical hydraulic conductivity and organic carbon content (Radian, 1994). At OU 4, a site that has hydrogeologic similarities to OU 2, the ratio of the horizontal to vertical conductivity was high, indicating strongly anisotropic flow conditions in the shallow groundwater system (USGS, 1992). On the basis of hydrogeologic and geotechnical data at OU 2, groundwater appears to be moving primarily in the shallower, upper portions of the shallow groundwater system, and vertical percolation through the subjacent lower permeability sediments appears to be limited. Notwithstanding the complexities of the subsurface at OU 2 and an apparent lack of lateral correlation in the coarse-grained units, the coarser-grained units appear to have good lateral hydraulic connection.

2.1.3 Nature and Extent of Contamination at OU 2

The following discussion focuses on soil and groundwater contamination beneath OU 2 and provides a summary of the nature, extent, and concentrations of contamination near the source area and in hydraulically downgradient, off-base locations. The soil analytical data are summarized from the RI work near the source area (Radian, 1992). The groundwater results include RI data, and subsequent continued groundwater monitoring. Additionally, some new wells near the Weber-Davis Canal have been installed and monitored (CH2M Hill, 1996). The organic compounds have been analyzed using EPA SW846 methods. The data were validated pertaining to adherence to field and laboratory QA/QC protocols but retain the laboratory-generated flags, or are not flagged.

2.1.3.1 Soil Contamination

Borehole soil samples were collected during the RI phase of work at OU 2 in the immediate vicinity of the trenches. CAHs, mostly TCE with lesser amounts of PCE and TCA were detected, primarily in upper zone sands and gravels near the trench locations (Radian, 1992). The distribution of TCE in vadose zone and some saturated zone soils near the source area is shown in Figure 2.15. The soil analytical results indicated higher

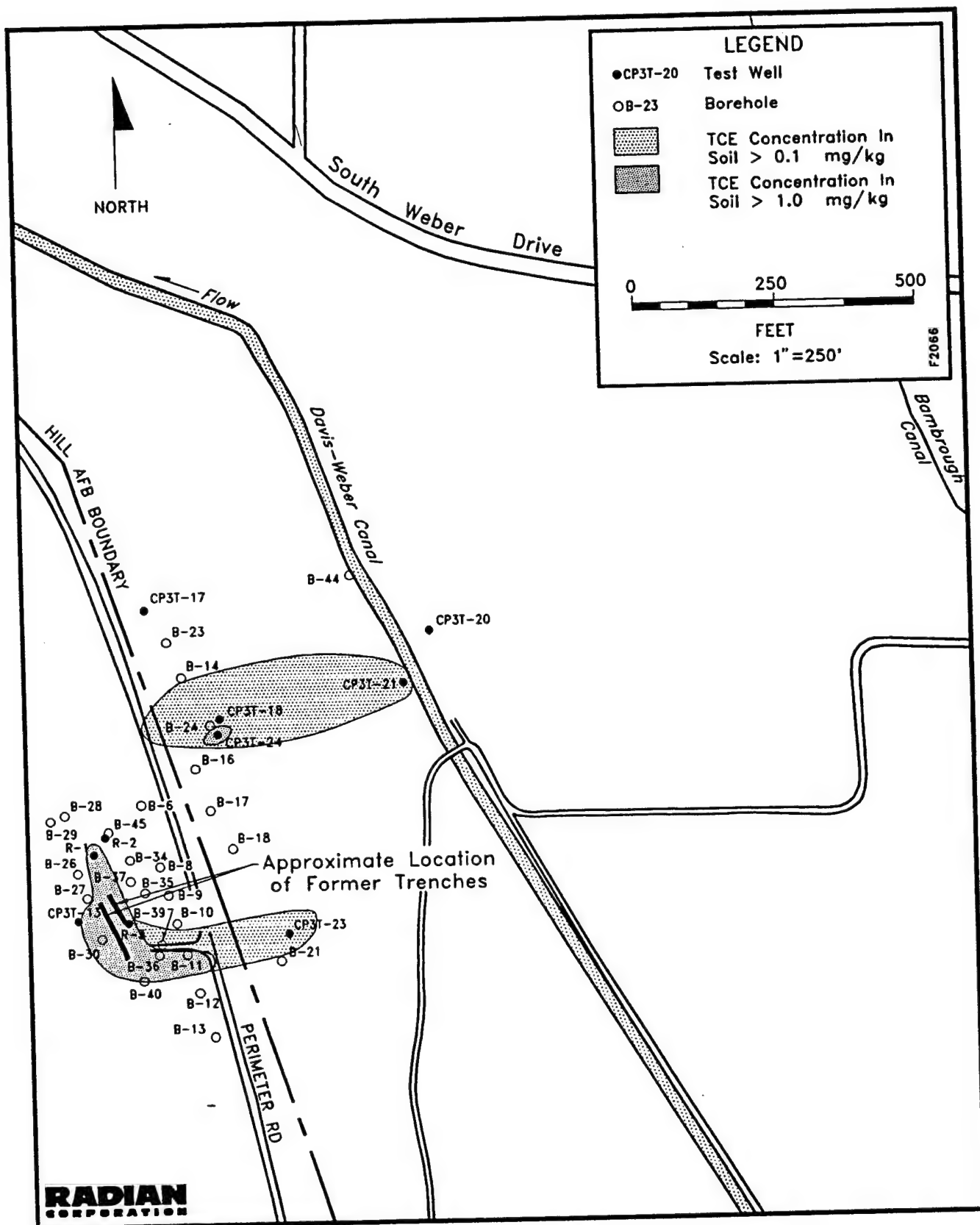


Figure 2.15 Areas of Elevated TCE in Soil at the Source

concentrations within sampled intervals below the water table. The pattern of soil contamination shown in the figure, particularly the contamination found north of the trenches, appears to indicate volatilization of the solvents from groundwater, or shallow groundwater contamination partitioning into the overlying soils along the hillside (Radian, 1992). Conversely, this also suggests the general absence of residual soil contamination at the source area.

Metals were not found to be compounds of concern in OU 2 soils. Only two metals (mercury and vanadium) were detected in subsurface soil samples at levels that were statistically higher than the mean concentration in background surface soil (Radian, 1994). Analytical results for TCLP leachates from surface and subsurface soils indicated the presence of beryllium, cadmium and chromium. Samples for metals were not collected in off-base areas.

2.1.3.2 Groundwater Contamination

Groundwater samples were collected from monitor wells, boreholes, and CPT/Hydropunch[®] probes during the fall 1992 investigation (Radian, 1994). Additional groundwater samples were collected from all accessible OU 2 wells over a two year period from May 1993 through February 1996 (CH₂M Hill, 1995, and CH₂M Hill, 1996). The identified source of the CAHs in groundwater at OU 2 are the DNAPLs beneath the disposal trenches at Chemical Disposal Pit 3 (Radian, 1992). Using the most current groundwater data collected in February 1996 (CH₂M Hill), the TCE plume has a surface area of approximately 35 acres, with most off-base (Figure 2.16). The lateral extent of the TCE plume varies seasonally, but has not changed much since 1993. More recently, additional monitoring points have been installed in downgradient areas near the Davis-Weber Canal and have given greater definition in these areas, and therefore, the higher concentration zones of the plume appear to have moved further north. Isoconcentration maps for PCE and TCA corresponding to the TCE data for February 1996 are shown in Figure 2.17 and 2.18, respectively. Analytical data for the individual monitoring points for the August 1995 and February 1996 sampling events are provided in Tables A.1 and A.2, Appendix A.

Besides TCE, the only CAH of relative importance to RNA to be detected with regularity is 1,2-dichloroethene (1,2-DCE). The distribution of DCE relative to TCE can provide an indication of ongoing biodegradation of TCE. In particular, the distribution of *cis* 1,2-DCE is most useful, because this isomer is preferentially produced through the biodegradation of TCE (Bouwer, 1994). In general, *cis* 1,2-DCE data were not reported in the various OU 2 documents for most site sampling events. However, upon request, the available raw data were made available to Hill AFB by the consultant. All of the locations where *cis* 1,2-DCE has been detected, and the corresponding concentrations, are

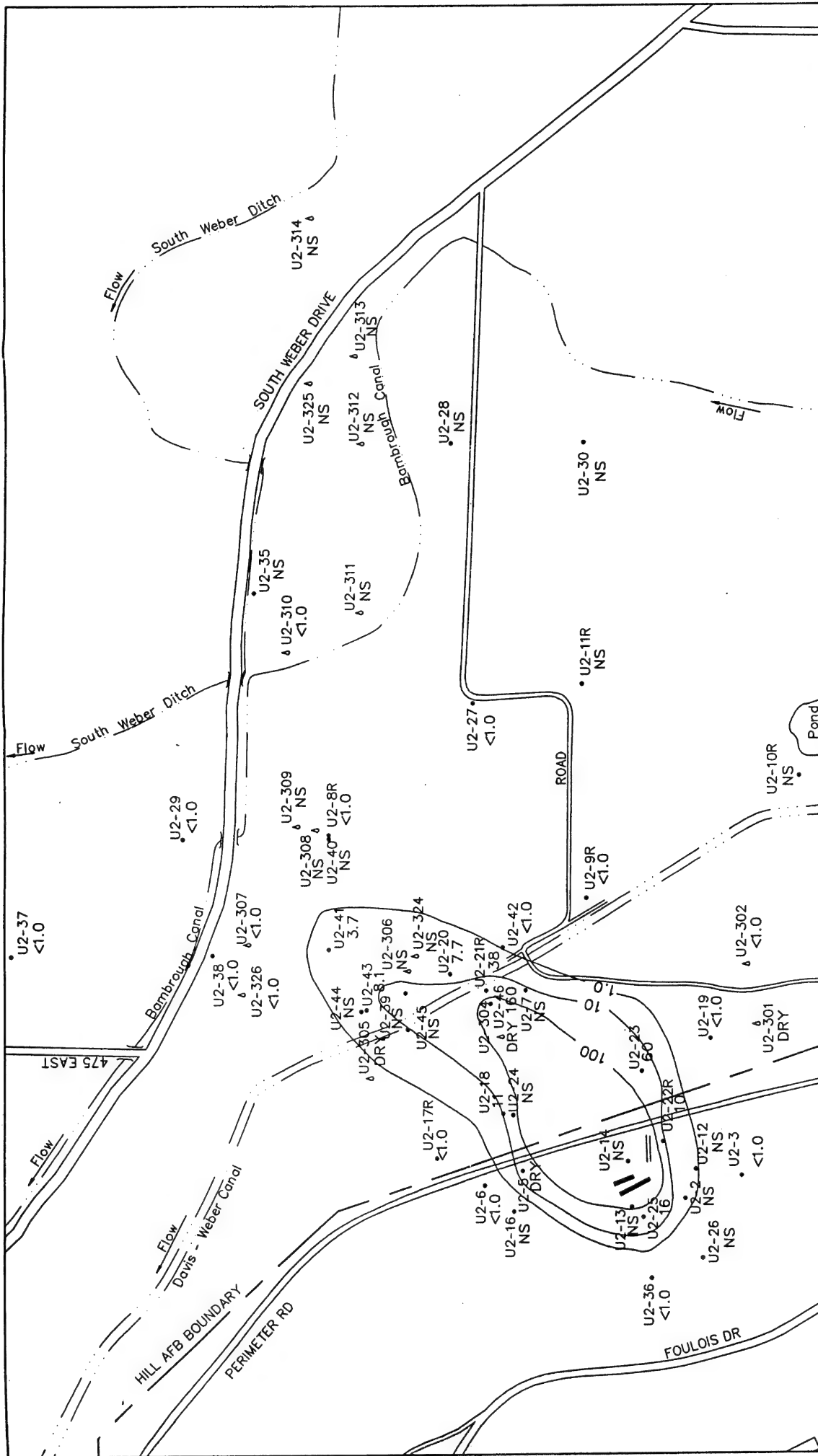
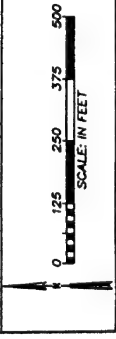


Figure 2.17
 LATERAL EXTENT OF PCE
 GROUNDWATER PLUME, FEB 96
 OPERABLE UNIT 2, HILL AIR FORCE BASE, UTAH

LEGEND

- MONITORING WELL LOCATION
- Δ SPRING LOCATION
- 5.8 PCE CONCENTRATION (µg/L)
- 1.0— PCE ISOCONCENTRATION CONTOUR (µg/L)
- NS NOT SAMPLED



shown in Table 2.1. The data in this table are raw data and have not been cross-checked for accuracy or correctness.

Some *cis* 1,2-DCE in shallow groundwater is a preliminary indication that some TCE is being degraded to 1,2-DCE. However, where detected, *cis* 1,2-DCE is generally detected at rather low concentrations relative to TCE, as can be seen by comparing Table 2.1 and Table 2.2. Generally, in the further downgradient sampling points where concentrations of TCE lower, the percentage of *cis* 1,2-DCE relative to TCE is greater (see Figure 2.16 for locations). The data indicate no clear temporal trends and concentrations generally fluctuate with time. However, there appears to be a general decreasing trend in TCE for sampling points nearer the source area (U2-5, U2-18). The fluctuation in CAH concentrations appears to be related to fluctuation in groundwater levels. As water levels from spring recharge rise near the source area and the far downgradient areas, TCE levels rise (CH₂M Hill, 1996). Conversely, as water levels rise near the canal area, TCE levels drop, perhaps due to dilution from canal leakage or the lag time in TCE pulses from the source area (CH₂M Hill, 1996).

The vertical plume dimensions were not delineated in any of the literature, however, as previously stated, the vertical extent and saturated thickness of dissolved-phase groundwater contamination in the shallow groundwater system appears to be limited. The saturated thickness of groundwater contamination is greatest near the source area DNAPLs. No estimate of the volume of contaminated aquifer matrix and groundwater were given in the literature reviewed.

2.1.3.3 Contaminant Transport and Preferential Pathways

The apparent, primary transport pathway at OU 2 is leaching from the trenches at Chemical Disposal Pit 3 into the soil/unsaturated zone, to shallow on-base groundwater with DNAPLs in depressions at the base of the saturated zone, then to off-base shallow groundwater and seeps. The analytical data for springs and seeps located along the hillside and at the base of the hillside indicate that the plume is discharging via this pathway. Apparently, the leading edge of the plume is stable and discharging, with only minor seasonal fluctuations in the far downgradient dimension. TCE has been detected sporadically at low concentrations in the shallow groundwater of the off-base floodplain north of South Weber Drive (U2-37).

As stated previously in Subsection 2.1.2.2, the plume morphology appears to have subsurface geologic and hydraulic controls, and preferential vertical migration appears to be limited because of the fine-grained sediments and lower hydraulic conductivity with depth. Fast flow channels or layers within the plume have not been quantitatively identified, but appear to exist. Aquifer parameter and vertical contaminant profiling data are insufficient to calculate meaningful estimates of average linear velocity and mass

Table 2.1
Concentrations of cis 1,2-Dichloroethene
Detected in OU 2 Groundwater (May 1993-February 1996)
Hill AFB, Utah

cis-1,2-DCE	May-93 (ug/L)	Aug-93 (ug/L)	Nov-93 (ug/L)	Feb-94 (ug/L)	May-94 (ug/L)	Aug-94 (ug/L)	Nov-94 (ug/L)	Feb-95 (ug/L)	Aug-95 (ug/L)	Feb-96 (ug/L)
U2-5	100 U	100 U	100 U	NA	3	20 U	NA	NA	5 U	NA
U2-18	12	11	25	52	50	50 U	10	20 U	22	24
U2-20	5	10	11	26	26	10 U	24	32	22	20
U2-21R	26	250	410	NA	330	220	330	420	400	440
U2-23	50 U	20 U	1 U	6	5	50 U	20U	5	5 U	1 U
U2-38	NA	NA	NA	NA	53	36	26	38	35	71
U2-41	NA	NA	NA	NA	NA	NA	NA	NA	25	30
U2-43	NA	NA	NA	NA	NA	NA	NA	NA	NA	56
U2-46	NA	NA	NA	NA	NA	NA	NA	NA	NA	620
U2-304	21	117	NA	NA	NA	NA	NA	NA	NA	NA
U2-307	5	3	5	3	2	1 U	3	14	1 U	NA
U2-324	5	23	NA	NA	1 U	1 U	1 U	1 U	1 U	NA
U2-326	NA	NA	NA	NA	NA	NA	NA	NA	NA	29

Note: See Table A.1 and A.2, Appendix A, for all August 1995 and February 1996 analytical data.

Table 2.2
Corresponding Concentrations of Trichloroethene
Detected in OU 2 Groundwater (May 1993-February 1996)
Hill AFB, Utah

TCE	May-93 (ug/L)	Aug-93 (ug/L)	Nov-93 (ug/L)	Feb-94 (ug/L)	May-94 (ug/L)	Aug-94 (ug/L)	Nov-94 (ug/L)	Feb-95 (ug/L)	Aug-95 (ug/L)	Feb-96 (ug/L)
U2-5	67000	67000	90000	NA	6400	8100	NA	NA	4400	NA
U2-18	3000	6800	11000	8900	7700	4500	4700	3700	1100	5700
U2-20	350	720	1500	1700	830	430	1100	600	910	1400
U2-21R	310	4300	12000	NA	6100	3900	7600	7700	9400	9200
U2-23	8200	12000	4400	4800	5200	2900	5400	7100	2800	6400
U2-38	NA	NA	NA	NA	170	84	110	150	120	230
U2-41	NA	NA	NA	NA	NA	NA	NA	NA	480	610
U2-43	NA	NA	NA	NA	NA	NA	NA	NA	NA	1700
U2-46	NA	NA	NA	NA	NA	NA	NA	NA	NA	32000
U2-304	3100	7000	NA	NA	NA	NA	NA	NA	NA	NA
U2-307	43	36	71.5	44	3.1	1 U	8.2	42	1 U	NA
U2-324	210	260	NA	NA	1 U	1 U	1 U	1 U	1 U	NA
U2-326	NA	NA	NA	NA	NA	NA	NA	NA	NA	310

Note: See Table A.1 and A.2, Appendix A, for all August 1995 and February 1996 analytical data.

flux. However, the hydraulic gradients are relatively high and change with the fluctuating groundwater levels, and therefore, the flow velocity and flux would be controlled and equally affected by changes in hydraulic gradient.

2.1.4 Groundwater Geochemistry

Shallow groundwater generally plots in the bicarbonate, mostly Ca- and slightly Mg-dominated area of the Piper plot (Figure 2.19). This general ionic chemistry appears to be indicative of a shallow, local groundwater flow system at OU 2, with recent recharge and limited cation exchange along the downgradient flowpath. Little data is available in the reviewed literature regarding electron acceptors. Apparently, dissolved oxygen and oxidation/reduction potential (ORP) measurements have not been taken. Limited sulfate and nitrate/nitrite data from earlier intrusive work indicated sulfate ranged from 2.2-110 mg/L and nitrate/nitrite ranged from 0.03-8.6 mg/L near the source area (Radian, 1992). The pH is generally in the range of 7 to 8 pH units.

Trace metal electron acceptors such as iron and manganese that facilitate some biological reactions and are indicative of oxidation/reduction conditions have been detected, but only manganese has been analyzed consistently. Generally, some dissolved manganese is present in groundwater within the higher CAH concentration portions of the plume, and appears to be naturally available in the soil/groundwater system (Table A.1, Appendix A). The presence of manganese at these locations suggests locally reducing conditions; however, filtered concentrations of manganese are generally less than unfiltered.

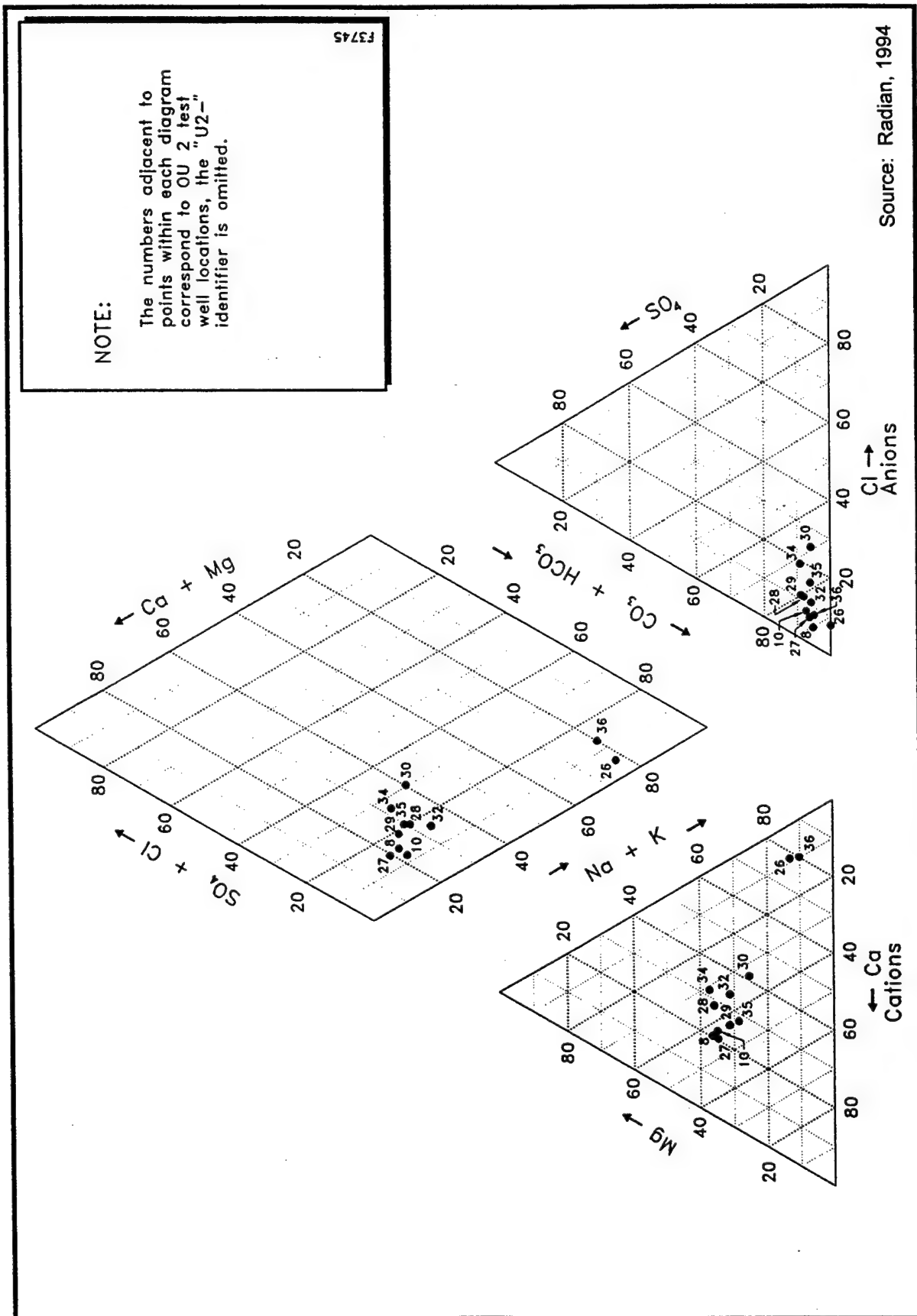


Figure 2.19 Water Types in the Shallow Groundwater System (filtered samples)

2.2 DEVELOPMENT OF CONCEPTUAL MODELS

A conceptual model of groundwater flow is a three-dimensional representation of a hydrogeologic system based on available geological, hydrological, climatological, and geochemical data. A site-specific conceptual model of groundwater flow is developed to provide an understanding of the mechanisms controlling contaminant transport. A conceptual model of RNA is developed to provide an understanding of the fate processes that bring about a total reduction in contaminant mass. Combined, the initial conceptual model of groundwater flow and RNA provides a foundation for formulating decisions regarding additional data collection and the potential for intrinsic remediation. The conceptual model for OU 2 will be used to aid in selecting additional data collection points and to identify appropriate data needs for modeling natural attenuation of CAHs.

Successful conceptual model development involves:

- Defining the problem to be solved;
- Integrating available data, including
 - Local geologic and topographic data,
 - Hydraulic data,
 - Site stratigraphic data
 - Primary contaminant and daughter product concentration and distribution data,
 - Geochemical concentration and distribution data,
 - Distribution and values of DO, ORP, pH, etc., and
 - Geotechnical data (e.g., native organic carbon, etc.)
- Evaluating contaminant fate and transport characteristics;
- Identifying contaminant preferential pathways;
- Identifying the occurrence and types of active biodegradation;
- Identifying potential receptors and exposure points; and
- Determining additional data requirements.

2.2.1 RNA and Solute Transport Models

After a site has been adequately characterized, fate and transport analyses can be performed to determine the potential for contaminant migration and human and ecological receptor pathway completion. Groundwater flow and solute transport models have proven useful for predicting plume migration and contaminant attenuation by biodegradation. Analytical and numerical models are available for modeling the fate and

transport of CAHs under the influence of advection, dispersion, sorption, and natural aerobic and anaerobic biodegradation. Analytical models derived from advection-dispersion equations [e.g., models such as those presented by Wexler (1992) and van Genuchten and Alves (1982)] may be useful. However, because CAH biodegradation may be the result of different processes in different locations, it may be necessary to use a numerical model to incorporate spatial variability in contaminant decay rates.

An accurate estimate of the potential for natural biodegradation of chlorinated compounds in groundwater is important to consider when determining whether groundwater contamination presents a substantial threat to human health and the environment, and when deciding what type of remedial alternative will be most cost effective in eliminating or abating these threats. Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms degrade a variety of fuel hydrocarbons and chlorinated solvents (Lee, 1988; McCarty *et al.*, 1992). The following section discusses the biodegradation of CAHs.

2.2.2 Biodegradation of CAHs

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Wilson and Wilson, 1985; Miller and Guengerich, 1982; Nelson *et al.*, 1986; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990; Alvarez-Cohen and McCarty, 1991a, 1991b; DeStefano *et al.*, 1991; Henry, 1991; McCarty *et al.*, 1992; Hartmans and de Bont, 1992; McCarty and Semprini, 1994; Vogel, 1994). CAHs may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or any combination of these processes may be operating, although at many sites biodegradation of CAHs as electron acceptors appears to be the most important.

In a pristine aquifer, native organic carbon is utilized as an electron donor and DO is utilized first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbons or low-molecular-weight CAHs) is present, it also will be utilized as an electron donor. After the DO is consumed or in the absence of DO, organotrophic (derive carbon from organic matter) anaerobic microorganisms typically use native electron acceptors (as available) to facilitate biological reactions in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how CAH biodegradation is occurring. In addition, because CAHs may be used as electron acceptors or electron donors (in competition with other acceptors or donors),

isopleth maps showing the distribution of these compounds will also provide evidence of the types of biodegradation processes acting at a site.

As with BTEX, the driving force behind redox reactions resulting in CAH degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in CAH reduction and oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy. A more complete description of the main types of biodegradation reactions affecting CAHs is presented in the following subsections.

2.2.2.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom. Figure 2.20 illustrates the transformation of chlorinated ethenes via reductive dehalogenation. In general, reductive dehalogenation occurs by sequential dehalogenation from tetrachloroethene (PCE) to TCE to DCE to vinyl chloride (VC) to ethene. Depending on environmental conditions, this sequence may be interrupted, with other processes then acting on the products. During reductive dehalogenation, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

Reductive dehalogenation affects each of the chlorinated ethenes differently. Of these compounds, PCE is the most susceptible to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation because it is the least oxidized of these compounds. The rate of reductive dehalogenation also has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in PCE and TCE plumes that are undergoing reductive dehalogenation. Reductive dehalogenation has been demonstrated under anaerobic nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994).

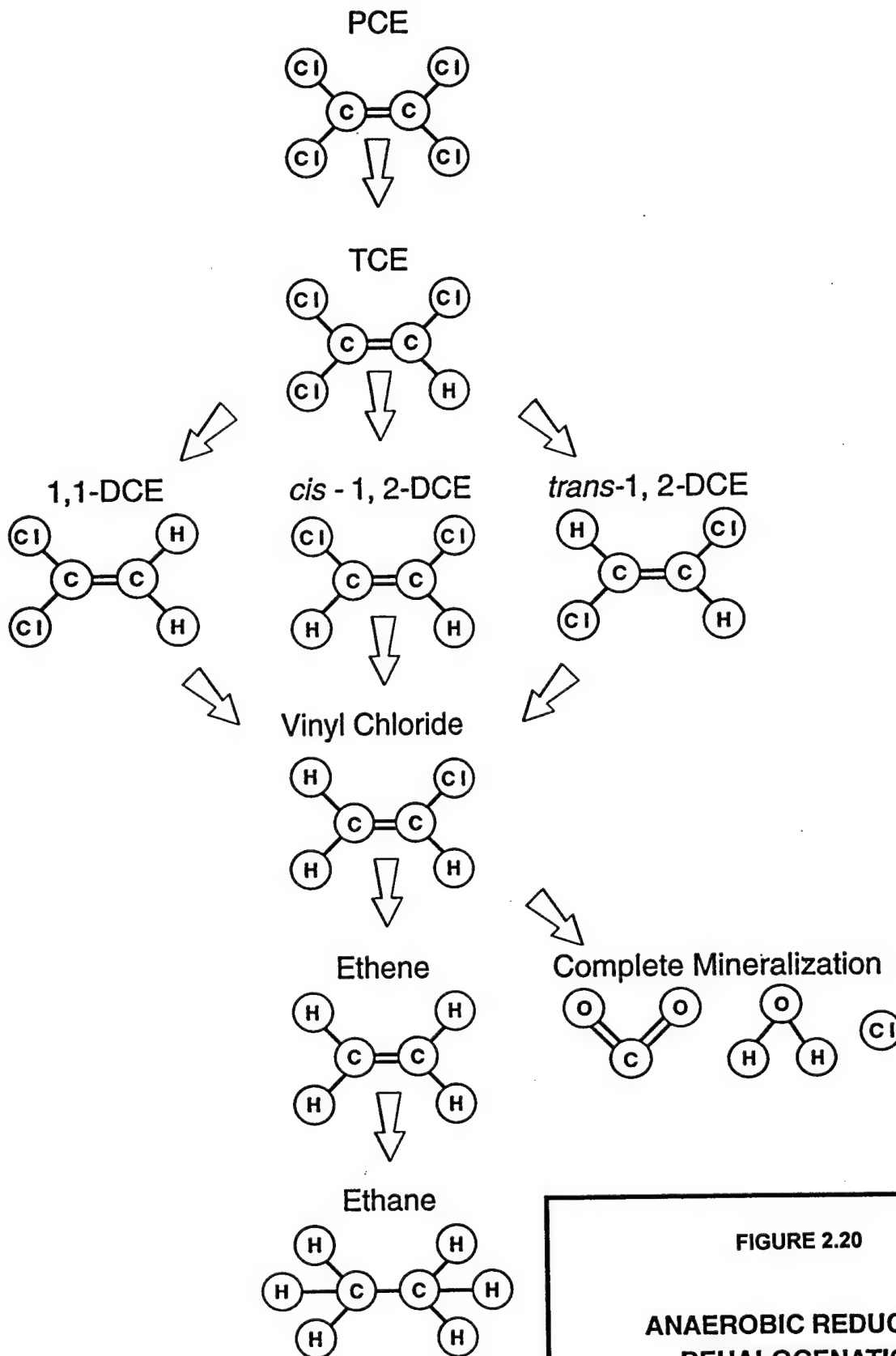


FIGURE 2.20

**ANAEROBIC REDUCTIVE
DEHALOGENATION**

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Because CAH compounds are used as electron acceptors, there must be an appropriate source of carbon (electron donor) for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources can include low molecular weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, or fuel hydrocarbons. In some anaerobic conditions dihydrogen can act as an electron donor, although small concentrations of complex organic compounds are required for growth (Paul and Clark, 1989).

2.2.2.2 Electron Donor Reactions

Under aerobic conditions some CAH compounds can be utilized as the primary substrate (i.e., electron donor) in biologically mediated redox reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. In contrast to reactions in which the CAH is used as an electron acceptor, only the least oxidized CAHs can be utilized as electron donors in biologically mediated redox reactions. McCarty and Semprini (1994) describe investigations in which VC and 1,2-DCA were shown to serve as primary substrates. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. In addition, Bradley and Chapelle (1996) show evidence of mineralization of VC under iron-reducing conditions so long as there is sufficient ferric iron available for biological processes. Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE. Aerobic metabolism of VC may be characterized by a loss of VC mass, a decreasing molar ratio of VC to other CAH compounds, and the presence of chloromethane.

2.2.2.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, the degradation of the CAH is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the CAH. In some cases, cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. Aerobic biodegradation pathways for chlorinated ethenes are illustrated in Figure 2.21. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994).

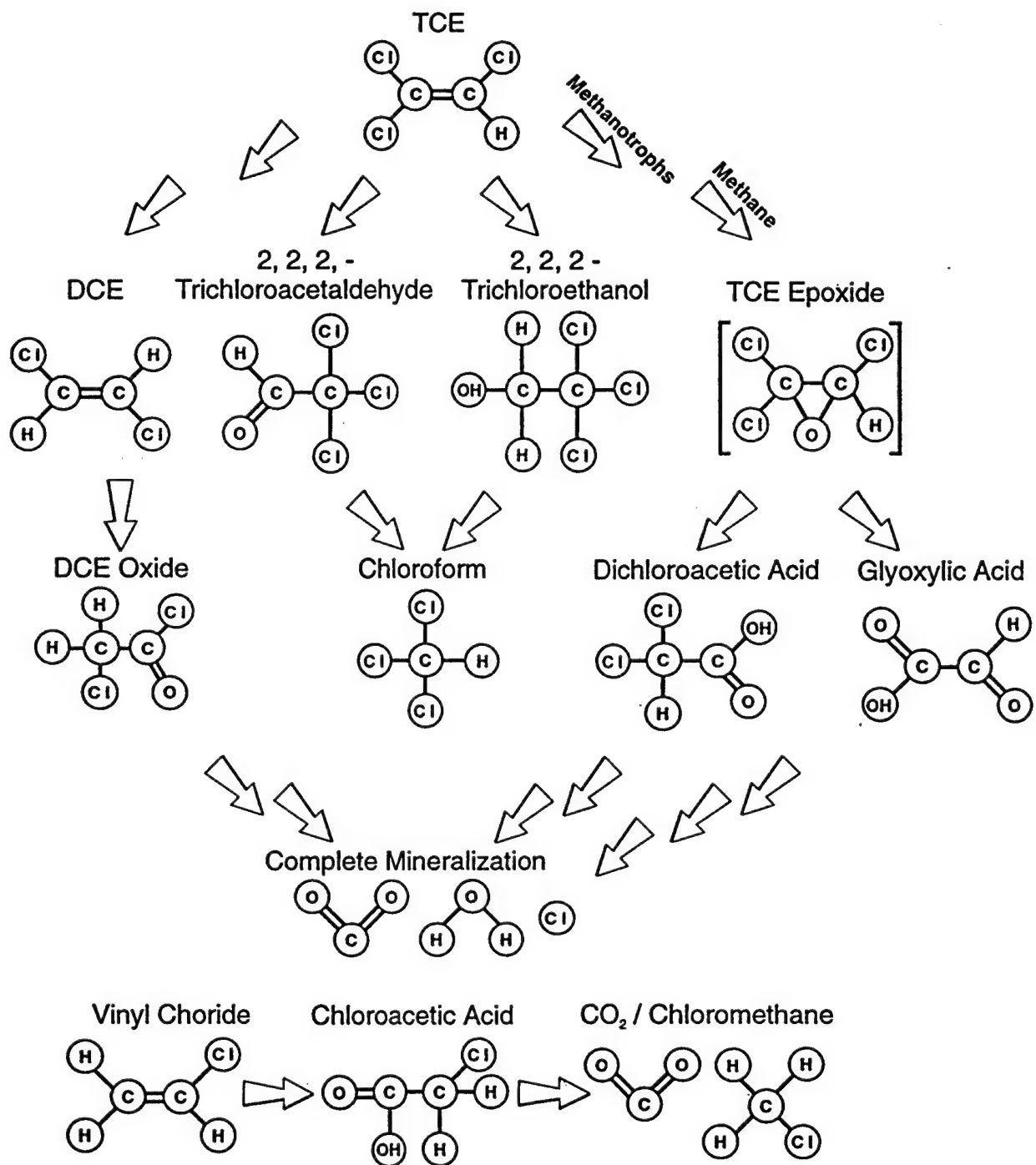


FIGURE 2.21

AEROBIC DEGRADATION

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Vogel (1994) further elaborates that the cometabolism rate increases as sequential dehalogenation proceeds from TCE to VC.

In the cometabolic process, TCE is indirectly transformed by bacteria as they use BTEX or another carbon substrate to meet their energy requirements. Therefore, TCE does not enhance the degradation of BTEX or other carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. It is likely that depletion of suitable substrates (BTEX or other organic carbon sources) limits cometabolism of CAHs.

2.2.2.4 Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of organic (native and/or anthropogenic) carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being utilized. Individual plumes may exhibit all three types of behavior in different portions of the plume. The different types of plume behavior are summarized below.

2.2.2.4.1 Type 1 Behavior

Type 1 behavior occurs where the primary substrate is anthropogenic carbon (e.g., BTEX or landfill leachate), and this anthropogenic carbon drives reductive dehalogenation. When evaluating intrinsic remediation of a plume exhibiting type 1 behavior the following questions must be answered:

- 1) Does electron donor supply exceed demand [i.e., is the electron donor (e.g., BTEX) supply adequate]?
- 2) Will the CAH plume "strangle" before it "starves" [i.e., will it run out of CAHs (electron acceptors) before it runs out of primary substrate (anthropogenic carbon)]?
- 3) What is the role of competing electron acceptors?
- 4) Is VC oxidized, or is it reduced?

2.2.2.4.2 Type 2 Behavior

Type 2 behavior dominates in areas that are characterized by relatively high native organic carbon concentrations, and this carbon source drives reductive dehalogenation (i.e., the primary substrate for microorganism growth is native organic carbon). When

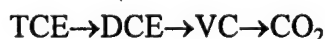
evaluating intrinsic remediation of a type 2 chlorinated solvent plume, the same questions as those posed in the description of type 1 behavior must be answered.

2.2.2.4.3 Type 3 Behavior

Type 3 behavior dominates in areas that are characterized by low native and/or anthropogenic carbon concentrations, and DO concentrations that are greater than 1.0 mg/L. Under these conditions the plume is aerobic, and reductive dehalogenation will not occur. Thus there is no reductive dehalogenation of PCE, TCE, and DCE. Biodegradation of TCE and its daughter products may proceed via the much slower process of cometabolism, but will be limited by the low concentrations of native or anthropogenic carbon. The most significant natural attenuation mechanisms for the more oxidized CAHs will be advection, dispersion, and sorption. However, the less oxidized CAHs such as VC, and possibly DCE, could be oxidized under these conditions.

2.2.2.4.4 Mixed Behavior

As previously mentioned, a single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of CAH plumes. For example, Wiedemeier *et al.* (1996) describe a plume at Plattsburgh AFB, New York that exhibits type 1 behavior in the source area and type 3 behavior downgradient from the source. The best scenario involves a plume in which TCE and DCE are reductively dehalogenated (type 1 or 2 behavior), then VC is oxidized (type 3 behavior), either aerobically or anaerobically (via iron reduction). VC is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in this type of plume.



In general, the TCE, DCE, and VC may attenuate at approximately the same rate, and thus these reactions may be confused with simple dilution. Note that no ethene is produced during this reaction. VC is removed from the system much faster under these conditions than it is under VC-reducing conditions.

A less desirable scenario involves a plume in which all CAHs are reductively dehalogenated (type 1 or 2 behavior). VC is reduced to ethene, which is further reduced to ethane. The following sequence of reactions occur in this type of plume.



In this type of plume, DCE and VC degrade more slowly than TCE, and thus they tend to accumulate. This type of reductive dehalogenation is the described by Freedman and Gossett (1989).

2.2.2.4.5 Abiotic Transformations

In general, abiotic transformations of CAHs are not significant relative to other natural attenuation processes. However, 1,1,1-TCA can be transformed abiotically to form 1,1-DCE (and ultimately VC) or acetic acid, although the process is relatively slow, with a half-life on the order of one year (Bouwer, 1994; Vogel, 1994). Such processes can complicate the study of CAH transformation, particularly if conditions are such that the half-life of the abiotic process is similar to that of biological processes in effect.

2.2.3 Preliminary Conceptual Model

The hydrogeology at OU 2 is generally well defined. Geologic and hydrogeologic cross-sections were shown in Figures 2.5, 2.6, 2.7, 2.8, and 2.9. The deposits are primarily fine-grained silts and clays with interbedded coarser-grained sands and gravels that vary laterally and with depth, but become progressively more fine grained with depth. The subsurface stratigraphy has been modified substantially by slumping. This slumping combined with the complex depositional environment has created a heterogeneous subsurface with lateral discontinuities. Groundwater moves laterally in the interfingering layers of fine-grained and coarse-grained sediment in the shallower, upper portions of the shallow groundwater system, and the contamination is constrained to the near-surface hillside sediments. Vertical migration appears to be limited with depth by finer-grained, lower hydraulic conductivity sediments. Groundwater is mostly shallow along the hillside, and flow is north-northeast and downslope toward the valley.

The plume morphology and groundwater flow paths appear to be the result of subsurface geologic and/or hydraulic controls. CAHs, primarily TCE, as DNAPLs have leached downward from the disposal trenches through the unsaturated/saturated zone to the depressed surface of a basal clay. Groundwater with dissolved-phase CAHs resulting from interaction with the DNAPLs and possibly residual contamination in the unsaturated zone has migrated downgradient along the hillside under the influence of steep hydraulic gradients. Some of the more shallow contaminated groundwater discharges to seeps and springs located along the hillside and at the base of the hillside. However, contaminated groundwater has migrated slightly beyond the base of the hillside into the valley flood-plain deposits. This location slightly north of South Weber Drive marks the leading edge of the plume (TCE concentrations greater than 1 ug/L), and the plume appears to stabilize at approximately 4,450 feet-msl, though the terminus fluctuates slightly due to apparent seasonal water level response. Shallow groundwater in the valley may be hydraulically isolated from the deeper Sunset Aquifer. Based on the information above, OU 2 could be modeled as an unconfined, heterogeneous, anisotropic aquifer under either steady-state or transient-state flow conditions.

The CAH plume at OU 2 is well defined, and can be characterized as having a high contaminant mass but possibly a lower volumetric flow rate. Mechanisms of RNA such as advection, dispersion, dilution, discharge, evapotranspiration, volatilization, and biodegradation probably are reducing concentrations or removing contaminant mass within the plume. Discharge and vadose zone processes including evapotranspiration may be more important in reducing contaminant mass in groundwater than biodegradation.

Both aerobic and anaerobic biodegradation as well as abiotic degradation may be occurring in the OU 2 plume, but degradation appears to be progressing rather slowly, perhaps due to limited carbon and/or oxygen. PCE is still present, indicating that not all PCE has been converted to TCE through reductive dehalogenation since the disposal trenches were last used in 1975. The data suggest that some TCE is being reductively dehalogenated or aerobically biodegraded (cometabolism) to 1,2-DCE; although, the low ratio of 1,2-DCE to TCE and the apparent general lack of VC indicate that conditions are not strongly reducing (Table 2.1 and 2.2). The formation of some 1,1-DCE may indicate that the abiotic transformation of TCA is occurring (Appendix A).

Plume behavior under these conditions would be Type 1 or Type 2 depending on the source of carbon driving reduction dehalogenation, or Type 3 where sufficient dissolved oxygen is available. The plume at OU 2 appears to exhibit mixed type behavior but may be "carbon starved", thereby limiting reductive dehalogenation and cometabolism. Higher concentrations of 1,2-DCE relative to TCE in the downgradient areas indicate that reductive dehalogenation may be more effective in these areas. Perhaps more carbon substrate (electron donor) is available. Also, dissolved oxygen may be available in the downgradient areas, where groundwater is shallow and some emerges in springs. VC, and possibly DCE, could oxidize under these conditions. The limited amount of VC being produced through reductive dehalogenation (U2-41, U2-43) probably aerobically degrades or volatilizes in the vicinity of the springs (Appendix A). The availability of carbon, DO, ORP, and other important geochemical indicators would be clarified by the sampling of protocol parameters.

Because the plume appears to lack adequate carbon, the OU 2 plume would be a good candidate for carbon addition. the rate of biodegradation could increase substantially through carbon addition because other environmental factors at the site such as limited competing electron acceptors and the potential reducing conditions resulting from the containment wall would enhance progressive dehalogenation of the CAHs. At worst, PCE and TCE could convert to *cis* 1,2-DCE without complete degradation to VC. If VC were to form, it is likely that it would completely degrade to innocuous by-products or volatilize in this hydrogeological environment.

The transport and fate of the dissolved CAHs in groundwater could be investigated using analytical methods and/or numerical solute-transport modeling. Because the plume appears to be stable, mass loss within the plume from biodegradation, discharge, volatilization, etc., is more important than advective contaminant transport. Therefore, modeling efforts would focus on developing a total water budget and mass budget for the plume. However, the effects of the new containment wall will complicate this analysis. Data collection and analytical requirements are discussed in Section 3 of this work plan.

SECTION 3

COLLECTION OF ADDITIONAL DATA

To complete a demonstration and to document that RNA of chlorinated solvents is occurring at OU 2, some additional site-specific physical and chemical hydrogeologic data are needed to supplement the available site data. Many of the necessary measurements and analyses (listed below) have been performed during the site characterizations at OU 2; however, gaps in the available data do exist. In addition, some of the data are to be collected specifically to assess the potential for the use of RNA as viable remedial alternative.

Physical hydrogeologic characteristics required to fully evaluate RNA at OU 2 include:

- Depth to groundwater and screened intervals of site monitoring wells;
- Locations and screened intervals of downgradient domestic wells and their uses;
- Locations of receptor exposure points and potential for impact;
- Locations and rates of groundwater recharge and discharge;
- Locations and rates of evapotranspiration and volatilization;
- Areas of constant hydraulic head (for modeling);
- Horizontal and vertical hydraulic gradients and the distribution of hydraulic head;
- Aquifer saturated thickness and physical boundaries;
- Hydraulic conductivity as determined through slug tests and downhole flow meter tests;
- Identification of preferential migration pathways and estimates of migration rates;
- Estimates of dispersivity, where possible;
- Stratigraphic and geochemical analysis of subsurface media; and
- Groundwater temperature.

Chemical hydrogeologic characteristics required to fully evaluate RNA include:

- DO concentrations;
- Specific conductance;
- pH;
- ORP;
- Carbon dioxide concentrations;
- Total organic carbon (TOC) and, if possible, forms of carbon; and
- Additional chemical analysis of water and soil samples for the parameters listed in Table 3.1.

These physical and chemical hydrogeological parameters are needed to further develop and refine the site conceptual model of RNA and to aid in developing and calibrating the groundwater flow portion of a site-specific fate and transport model. In addition to the listed physical and chemical data, biological data may be collected through microcosm studies. These data can provide direct evidence of intrinsic bioremediation if properly designed and interpreted. Microcosms are discussed in Subsection 3.6.

There are gaps in the chemical and physical data that preclude a more thorough understanding of RNA at OU 2. Temporal, spatial, and analytical gaps in the available groundwater chemical data would be clarified by additional sampling for the parameters listed in Table 3.1. Parsons ES recommends sampling many of the existing monitoring points to gain a better understanding of the active biodegradation processes, prior to intrusive work (soil sampling, microcosms, monitoring points, etc.) at the site. For consistency and comparison, the 13 sampling points listed in Table 2.1 should be sampled. The furthest downgradient sampling location (U2-37) also should be sampled (Figure 2.16). In addition, sampling is recommended for several upgradient or cross-gradient locations (e.g., U2-36, U2-17R, U2-40, U2-308). Other monitoring points could be sampled at the discretion of Hill AFB. For additional sampling at the site, it is important that DO and ORP are measured. It also is important that the 1,2-DCE analyses are separated into the individual isomers (*cis* and *trans*), and that analytical detection limits are sufficiently low to confirm the presence of these compounds and other TCE degradation products. Concentration contour (isopleth) maps and downgradient profiles of the data will facilitate a more thorough evaluation of the biodegradation processes in effect. The spatial and vertical variation of groundwater flow velocity should also be determined to evaluate fast flow zones and potential migration rates at the site. In

TABLE 3.1
ANALYTICAL PROTOCOL FOR
GROUNDWATER AND SOIL SAMPLES
Hill Air Force Base, Utah

MATRIX Analyte	METHOD	FIELD (F) OR FIXED-BASE LABORATORY (L)
WATER		
Total Iron	Colorimetric, Hach Method 8008	F
Ferrous Iron (Fe^{2+})	Colorimetric, Hach Method 8146	F
Ferric Iron (Fe^{3+})	Difference between total and ferrous iron	F
Manganese	Colorimetric, Hach Method 8034	F
Sulfate	Colorimetric, Hach Method 8051	F
Nitrate	Titrimetric, Hach Method 8039	F
Nitrite	Titrimetric, Hach Method 8507	F
ORP	A2580B, direct-reading meter	F
Oxygen	Direct-reading meter	F
pH	USEPA method E150.1/SW9040, direct-reading meter	F
Conductivity	USEPA method E120.1/SW9050, direct-reading meter	F
Temperature	USEPA method E170.1, direct-reading meter	F
Carbon Dioxide	Titrimetric, Hach Method 1436-01	F
Alkalinity (Carbonate [CO_3^{2-}] and Bicarbonate [HCO_3^-])	F = Titrimetric, Hach Method 8221 L = USEPA Method 310.1	F L
Nitrate + Nitrite	USEPA Method 353.1	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Methane, Ethane, Ethene	RSKSOP-147 ^u	L
Dissolved Organic Carbon	RSKSOP-102	L
VOCs (BTEX, CAHs, chloroform, chloromethane)	RSKSOP-148	L
SOIL		
Total Organic Carbon	RSKSOP-102 & RSKSOP-120	L
Moisture	ASTM D-2216	L
VOCs (BTEX + CAHs)	RSKSOP-124, modified	L

^u RSKSOP = Robert S. Kerr Laboratory (now NRMRL) Standard Operating Procedure. See Appendix B for Solid Waste (SW) methods.

NOTE: Additional analyses (as indicated in Appendix B) also may be performed at the discretion of Parsons ES and USEPA NRMRL personnel.

general, data on the location and rates of recharge, discharge, volatilization, and carbon content are lacking.

Thorough and complete physical, chemical, and biological data will allow a better determination of what biodegradation processes are active and where they are active, and will provide information necessary for meaningful and accurate fate and transport modeling. General and inorganic groundwater chemical parameters [e.g., DO, nitrate, iron, sulfate, and chloride] are measured to evaluate active biodegradation via the pathways discussed in Subsection 2.2.2. Concentrations of DO are indicative of aerobic versus anaerobic conditions. Nitrate and sulfate decreases (reduction to nitrite and hydrogen sulfide) in the plume relative to the non-contaminated areas may be indicative of reductive dehalogenation. Ferrous iron may indicate iron-reducing conditions. Chloride ion increases in the plume relative to the non-contaminated areas may indicate de-chlorination by anaerobic and aerobic biological processes. Elevated carbon dioxide relative to background may indicate complete mineralization of CAHs, as it is the innocuous by-product of the biodegradation pathways. However, carbon dioxide also is abundantly produced by soil zone and geochemical processes. ORP is measured to help evaluate the potential for reductive dehalogenation or oxidation, and is an indicator parameter during well purging (along with DO, temperature, pH, and conductivity). Chloromethane, methane, ethane, and ethene are measured for evidence of complete dehalogenation of CAHs. Chloromethane may be indicative of the aerobic biodegradation of VC and the anaerobic biodegradation of DCA. Ethane and ethene are by-products of anaerobic reductive dehalogenation. Relative concentrations and changes in the concentrations of these VOCs also can be used to further evaluate the ongoing processes, as discussed in Subsection 2.2.2. Additional chemical analyses not listed in Table 3.1, or geotechnical analyses, may be performed at the discretion of Hill AFB. Additional analytes that may be tested are listed in Appendix E.

The following sections describe the recommended procedures to be followed when collecting additional site-specific data through intrusive investigation. However, additional intrusive work at OU 2 solely for the purposes of RNA is not recommended until further groundwater analytical data to characterize the active biological processes are evaluated. Additional intrusive investigation may be recommended after analysis of the sampling of existing monitoring points for the specific parameters listed in Table 3.1. If intrusive investigation is warranted, a work plan addendum will be prepared to address the specific locations and data to be collected. Recommended procedures to collect soil core samples are described in Section 3.1. Soil analyses are largely performed to evaluate the distribution and concentrations of organic carbon, and for soil microcosms. Procedures for the installation of new monitoring points are described in Section 3.2. Procedures to collect groundwater grab samples and to sample groundwater monitoring wells, surface water, and newly installed groundwater monitoring points are described in

Section 3.3. Sample handling procedures are described in Section 3.4, and procedures to measure aquifer parameters (e.g., hydraulic conductivity, flow velocity, etc.) are described in Section 3.5. CAH-degradation microcosm studies are discussed in Section 3.6.

3.1 SOIL SAMPLING AND ANALYSIS

The following sections describe soil sampling, sample collection techniques, equipment decontamination procedures, site restoration, and management of investigation-derived waste materials.

3.1.1 Soil Sampling Locations and Analyses

Additional soil sampling is not proposed until additional groundwater sampling is performed. In the event that soil samples are collected, a minimum of two samples will be obtained from each location. One sample will be obtained at the water table, and one will be obtained beneath the water table. Additional samples and sampling intervals may be selected at the discretion of the field scientist. Soil samples should be collected above the water table for analysis of VOCs where soil sources of groundwater contamination are suspected. However, the main purpose of soil sampling will be to determine aquifer matrix TOC concentrations and to collect cores for microcosms. If possible, at least two saturated soil samples from locations upgradient, crossgradient, or far downgradient from the contaminant source will be analyzed for these two parameters. Soil microcosm results from another Hill AFB OU may be applicable to OU 2, and therefore, may not be necessary.

A portion of each sample will be used to measure soil headspace, while another portion of selected samples will be sent to the laboratory for analytical analysis. Each laboratory soil sample will be placed in an analyte-appropriate sample container and hand-delivered to the field laboratory personnel for analysis. Each headspace screening sample will be placed in a sealed plastic bag or mason jar and allowed to sit for at least 5 minutes. Soil headspace will then be determined using an organic vapor meter (OVM), and the results will be recorded in the field records by the field scientist.

3.1.2 Sample Collection Using the Geoprobe® System

Soil samples will be collected using a Geoprobe® system (or similar push technology system), which is a hydraulically powered percussion/probing machine capable of advancing sampling tools through unconsolidated soils. This system allows rapid collection of soil, soil gas, or groundwater samples at shallow depths while minimizing the generation of investigation-derived waste materials. Figure 3.1 shows a diagram of the Geoprobe® system.

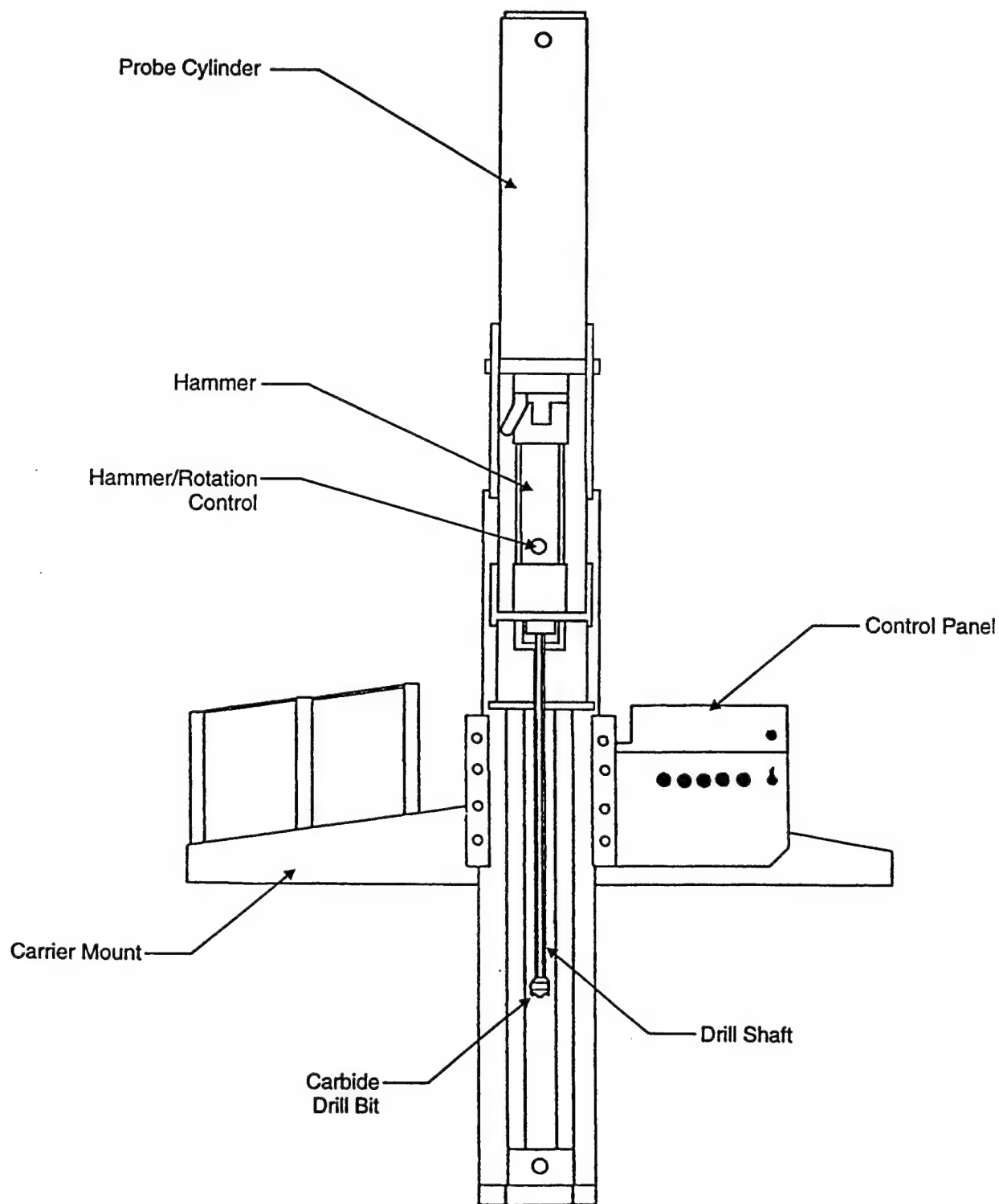


FIGURE 3.1

**CROSS-SECTION
OF GEOPROBE®**

Hill Air Force Base, Utah

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Soil samples will be collected using a probe-drive sampler. The probe-drive sampler serves as both the driving point and the sample collection device and is attached to the leading end of the probe rods. To collect a soil sample, the sampler is pushed or driven to the desired sampling depth, the drive point is retracted to open the sampling barrel, and the sampler is subsequently pushed into the undisturbed soils. The soil cores are retained within brass, stainless steel, or clear acetate liners inside the sampling barrel. The probe rods are then retracted, bringing the sampling device to the surface. The soil sample can then be extruded from the liners for lithologic logging, or the liners can be cut to the desired length, capped, and submitted to the analytical laboratory for testing of the undisturbed samples.

If the probe-drive sampling technique described above is inappropriate, inadequate, or unable to efficiently provide sufficient soil samples for the characterization of the site, continuous soil samples will be obtained from conventional soil boreholes using a hand auger or similar method judged acceptable by the field scientist. Procedures will be modified, if necessary, to ensure good sample recovery.

The field scientist will be responsible for observing all field investigation activities, maintaining a detailed descriptive log of all subsurface materials recovered during soil coring, photographing representative samples, and properly labeling and storing samples. An example geologic boring log form is presented as Figure 3.2. The descriptive log will contain:

- Sample interval (top and bottom depth);
- Sample recovery;
- Presence or absence of contamination (as indicated by OVM readings);
- Lithologic description, including relative density, color, major textural constituents, minor constituents, porosity, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, relative permeability, and any other significant observations; and
- Depths of lithologic contacts and/or significant textural changes measured and recorded to the nearest 0.1 foot.

Base personnel will be responsible for identifying the location of all utility lines, fuel lines, or any other underground infrastructure prior to any sampling activities. All necessary digging permits will be obtained through Base personnel prior to mobilizing to the field. If necessary, Base personnel also will be responsible for acquiring drilling and Figure 3.2

monitoring point installation permits for the proposed locations. The environmental consultant will provide trained operators for the Geoprobe®.

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: _____ CONTRACTOR: _____ DATE SPUD: _____
 CLIENT: AFCEE RIG TYPE: _____ DATE CMPL.: _____
 JOB NO.: 729080 DRLG METHOD: _____ ELEVATION: _____
 LOCATION: HILL, AFB BORING DIA.: _____ TEMP: _____
 GEOLOGIST: _____ DRLG FLUID: _____ WEATHER: _____
 COMENTS: _____

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample		Penet Res	PID(ppm)	ILV(ppm)	TOTAL BTX(ppm)	TPH (ppm)
					No.	Depth (ft)					
	1										
	5										
	10										
	15										
	20										
	25										
	30										
	35										

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB



Water level drilled

FIGURE 3.2

GEOLOGIC BORING LOG

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3.1.3 Datum Survey

The horizontal location of all soil sampling locations relative to established site coordinates will be measured by a surveyor. Horizontal coordinates will be measured to the nearest 0.1 foot. The elevation of the ground surface will also be measured to the nearest 0.1 foot relative to USGS msl data.

3.1.4 Site Restoration

After sampling is complete, each sampling location will be restored as closely to its original condition as possible. Holes created by the Geoprobe[®] in sandy soils similar to those found at the Base tend to cave in soon after extraction of the drive sampler. However, any test holes remaining open after extraction of the push rod will be sealed with bentonite chips, pellets, or grout to eliminate any creation or enhancement of contaminant migration pathways to the groundwater. Soil sampling using the Geoprobe[®] creates low volumes of soil waste. Soil not used for sampling will be placed in 55-gallon drums to await proper disposal by Base personnel. Alternate methods of soil waste disposal will be considered by the field scientist as recommended by Base personnel.

3.1.5 Equipment Decontamination Procedures

Prior to arriving at the site, and between each sampling location, probe rods, tips, sleeves, pushrods, samplers, tools, and other downhole equipment will be decontaminated using a high-pressure, steam/hot water wash. Only potable water will be used for decontamination.

Between each soil sample, the sampling barrel will be disassembled and decontaminated with Alconox[®] and potable water. The barrel will then be rinsed with deionized water and reassembled with new liners. Between uses, the sampling barrel will be wrapped in clean plastic or foil to prevent contamination.

All rinseate will be collected for proper disposal according to Base SOP for handling investigation derived waste. Alternate methods of rinseate disposal will be considered by the field scientist as recommended by Base personnel.

Potable water to be used during equipment cleaning, decontamination, or grouting will be obtained from one of the Base potable water supplies. Water use approval will be verified by contacting the appropriate facility personnel. The field scientist will make the final determination as to the suitability of site water for these activities. Precautions will be taken to minimize any impact to the surrounding area that might result from decontamination operations.

3.2 MONITORING POINT INSTALLATION

As with soil sampling, additional groundwater monitoring points are not proposed until additional groundwater sampling for the parameters in Table 3.1 is performed. In the event that monitoring points are installed at OU 2 to support a demonstration of RNA, the following installation protocol is recommended. The following sections describe monitoring point installation, completion intervals, development, and equipment decontamination procedures. If site conditions prevent installation of monitoring points, groundwater grab samples will be collected using the Geoprobe[®] apparatus.

3.2.1 Monitoring Point Locations and Completion Intervals

Monitoring point locations will be selected to evaluate the active processes of RNA, fill data gaps, monitor CAH migration, and provide the data necessary for successful implementation of a site-specific contaminant fate and transport model.

All monitoring points will be installed in the shallow groundwater system, unless new data merit otherwise. Monitoring points may be installed singly, or in clusters of up to three points. Monitoring point clusters will include one point that is screened at the top of the saturated zone and other points that will be screened at depths based on hydrogeologic conditions. Single monitoring points will be screened near the top of the saturated zone. With respect to clusters, shallow monitoring points will have a 3-foot screened interval, while deeper points will have 6-inch screens. The short screen lengths of 3 feet for shallow monitoring points and 6 inches for deep monitoring points will help mitigate dilution from potential mixing of contaminated and uncontaminated groundwater in the monitoring point screened interval. Adjustments to the depths and lengths of the screened intervals may be necessary in response to actual aquifer conditions and contaminant distribution identified during Geoprobe[®] testing.

3.2.2 Monitoring Point Installation Procedures

3.2.2.1 Pre-Placement Activities

All necessary digging, coring, and drilling permits will be obtained prior to field mobilization. In addition, all utility lines will be located, and proposed drilling locations will be cleared prior to any intrusive activities. Responsibilities for these permits and clearances are discussed in Section 3.1.2.

Water used in monitoring point installation and equipment cleaning will be obtained from one of the Base potable water supplies. Water use approval will be verified by contacting the appropriate facility personnel. The field scientist will make the final determination as to the suitability of site water for these activities.

3.2.2.2 Monitoring Point Materials Decontamination

Monitoring point installation and completion materials will be inspected by the field scientist and determined to be clean and acceptable prior to use. If not factory sealed, the well points, casing, and tubing will be cleaned prior to use with a high-pressure, steam/hot-water cleaner using approved water. Materials that cannot be cleaned to the satisfaction of the field scientist will not be used.

3.2.2.3 Installation and Materials

This section describes the procedures for installation of monitoring points. Monitoring points will be installed using either 0.375-inch Teflon[®] tubing connected to a 0.5-inch-diameter stainless steel screen or a 0.5-inch inside-diameter (ID)/0.75-inch outside-diameter (OD) polyvinyl chloride (PVC) screen and casing.

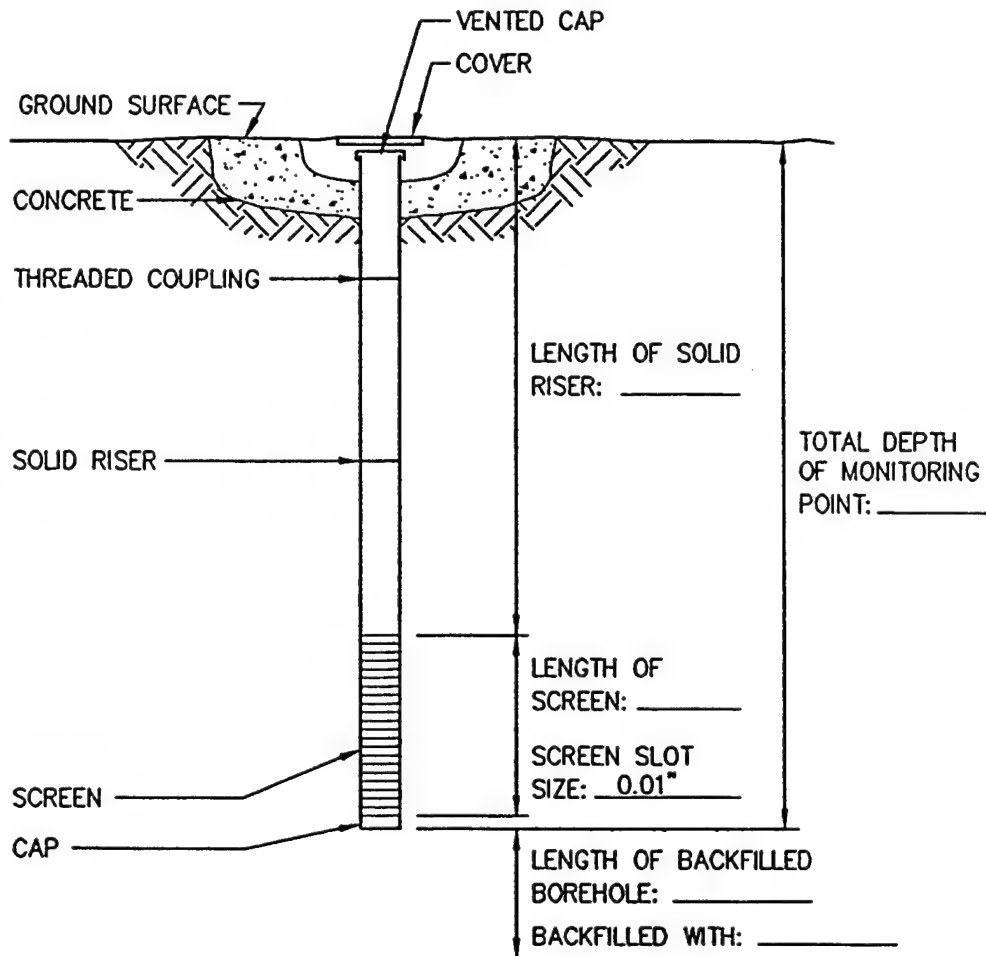
3.2.2.3.1 Deep Monitoring Points

The deep monitoring points will be installed in boreholes using the Geoprobe[®], or similar push-technology system. The deep monitoring points will be constructed of a sacrificial drive point attached to a length of 0.5-inch-diameter stainless steel mesh that will function as the well screen, which in turn will be connected to 0.375-inch Teflon[®] tubing.

To install the deep monitoring points, the borehole is punched and sampled to several feet above the target depth for the monitoring point. The probe rods are withdrawn from the borehole, and the soil sampler is replaced with the well point assembly. An appropriate length of Teflon[®] tubing is threaded through the probe rods and attached to the well point. The assembly is lowered into the borehole and then driven down to the target depth and sampling zone. The probe rods are removed, leaving the sacrificial tip, screen assembly, and tubing behind. The soil is likely to cave in around the screen and tube assembly; where this does not occur, silica sand will be emplaced to create a sand pack around the well point, and the borehole annular space around the tubing above the sand pack will be filled with granular bentonite or grout to seal it. Monitoring point construction details will be noted on a Monitoring Point Installation Record form (Figure 3.3).

MONITORING POINT INSTALLATION RECORD

JOB NAME HILL AIR FORCE BASE MONITORING POINT NUMBER _____
 JOB NUMBER 729080 INSTALLATION DATE _____ LOCATION _____
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 SCREEN DIAMETER & MATERIAL _____ SLOT SIZE _____
 RISER DIAMETER & MATERIAL _____ BOREHOLE DIAMETER _____
 CONE PENETROMETER CONTRACTOR _____ ES REPRESENTATIVE _____



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET
 BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET
 BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.3

MONITORING POINT INSTALLATION RECORD

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3.2.2.3.2 Shallow Monitoring Points

If subsurface conditions permit, shallow monitoring points will be constructed of 0.75-inch-OD/0.5-inch-ID PVC casing and well screen to provide additional water level information. Approximately 3 feet of factory-slotted screen will be installed for each shallow monitoring point. Shallow 0.5-inch-ID PVC monitoring points will be installed by punching and sampling a borehole with the Geoprobe[®]. Effective installation of the shallow monitoring points requires that the boreholes remain temporarily open after the borehole is punched and the rods are withdrawn. Upon removing the rods, the borehole depth will be measured to determine if the hole remains open. If the borehole is open, the 0.5-inch-ID PVC casing and screen will be placed at the appropriate depths. The annular space around the screen will be filled with sand filter pack, and the annulus around the casing will be filled with grout or bentonite. Monitoring point construction details will be noted on a Monitoring Point Installation Record form (Figure 3.3). This information will become part of the permanent field record for the site.

Monitoring point screens will be constructed of flush-threaded, Schedule 40 PVC with an ID of 0.5 inch. The screens will be factory slotted with 0.010-inch openings. Monitoring point screens will be placed to sample and provide water level information at or near the water table. Blank monitoring point casing will be constructed of Schedule 40 PVC with an ID of 0.5 inch. All monitoring point casing sections will be flush-threaded; joints will not be glued. The casing at each monitoring point will be fitted with a bottom cap and a top cap constructed of PVC.

If subsurface conditions do not permit the boreholes to stay open (i.e., if the formation collapses in the hole), monitoring points constructed of 0.375-inch Teflon[®] described in Section 3.2.2.3.1 will be installed. Should 0.5-inch-ID PVC shallow monitoring points not be installed, the only resulting data gap will be the lack of water level information for that particular location. The decision to install 0.5-inch-ID PVC monitoring points will be made in the field once the open-hole stability of subsurface soils and Geoprobe[®] equipment can be evaluated.

The field scientist will verify and record the total depth of the monitoring point, the lengths of all casing sections, and the depth to the top of all monitoring point completion materials. All lengths and depths will be measured to the nearest 0.1 foot.

3.2.2.4 Monitoring Point Completion or Abandonment

A number of the monitoring points will be completed above grade, and as needed, steel or PVC protective casing will be used to protect the well points from tampering and damage. The number of permanent monitoring points will be determined by the field scientist. The completion of the monitoring points will be similar to those protecting the existing monitoring wells unless otherwise specified by Base personnel.

Those monitoring points not completed with an external protective casing will be abandoned. The PVC casing and screen or Teflon[®] tubing will be extracted as far as possible and discarded. While holes created with the Geoprobe[®] in sandy soils similar to those found at the Base tend to cave in soon after extraction of the drive rod, any test holes remaining open after extraction of the casing will be sealed with bentonite chips, pellets, or grout to eliminate any creation or enhancement of contaminant migration pathways to the groundwater. After monitoring point completion or abandonment, each site will be restored as closely as possible to its original condition.

3.2.3 Monitoring Point Development and Records

The monitoring points will be developed prior to sampling to remove fine sediments from the portion of the formation adjacent to the well point screen. Development will be accomplished using a peristaltic pump. The pump will be inserted into or attached to the well point, and water will be removed until DO, pH, temperature, and specific conductivity stabilize. Monitoring point development will occur a minimum of 24 hours prior to sampling.

A development record will be maintained for each monitoring point. The development record will be completed in the field by the field scientist. Figure 3.4 is an example of a development record used for similar well installations. Development records will include:

- Monitoring point number;
- Date and time of development;
- Development method;
- Monitoring point depth;
- Volume of water produced;
- Description of water produced;
- Post-development water level and monitoring point depth; and
- Field analytical measurements, including pH and specific conductivity.

Development waters will be collected and held for proper disposal by Base personnel. Alternate methods of water disposal will be considered by the field scientist as recommended by Base personnel.

MONITORING POINT DEVELOPMENT RECORD

Job Number: _____ Job Name: Hill AFB
Location _____ By _____ Date _____
Well Number _____ Measurement Datum TOC

Pre-Development Information

Time (Start): _____

Water Level: _____

Total Depth of Well: _____

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature ($^{\circ}\text{F}$ $^{\circ}\text{C}$) _____
Specific Conductance ($\mu\text{S}/\text{cm}$) _____

Interim Water Characteristics

Gallons Removed _____

pH _____

Temperature ($^{\circ}\text{F}$ $^{\circ}\text{C}$) _____

Specific Conductance ($\mu\text{S}/\text{cm}$) _____

Post-Development Information

Time (Finish): _____

Water Level: _____

Total Depth of Well: _____

Approximate Volume Removed: _____

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature ($^{\circ}\text{F}$ $^{\circ}\text{C}$) _____
Specific Conductance ($\mu\text{S}/\text{cm}$) _____

Comments: _____

FIGURE 3.4

MONITORING POINT DEVELOPMENT RECORD

Hill Air Force Base, Utah

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3.2.4 Monitoring Point Location and Datum Survey

The location and elevation of the well points will be surveyed soon after completion. Horizontal coordinates will be measured to the nearest 0.1 foot relative to established Base coordinates. The elevation of the ground surface adjacent to the protective casing will be measured relative to the USGS msl datum. The ground surface elevation will be measured to the nearest 0.1 foot. A top-of-casing datum will be measured to the nearest 0.01 foot for all monitoring points constructed of 0.5-inch PVC casing and well screen. Because water levels cannot be measured through the well point tubing, no datum elevation, such as top of casing, will be measured for monitoring points constructed with Teflon[®] tubing.

3.2.5 Water Level Measurements

Water levels at existing monitoring wells and 0.5-inch PVC monitoring points will be measured within a short time period so that the water level data are comparable. The depth to water below the measurement datum will be measured to the nearest 0.01 foot using an electric water level probe or an oil/water interface probe.

3.3 GROUNDWATER SAMPLING PROCEDURES

This section describes the scope of work required for collection of groundwater quality samples. Samples will be collected from site monitoring wells (e.g., previously installed wells), newly installed groundwater monitoring points, springs, and at any grab-sample locations. A peristaltic pump or bladder pump with dedicated high-density polyethylene (HDPE) tubing will be used to collect groundwater samples at all wells and monitoring points. A Grundfos[®] Redi-Flo II[®] pump may be used for monitoring well purging prior to sampling. In order to maintain a high degree of QC during this sampling event, the procedures described in the following sections will be followed.

Sampling will be conducted by qualified scientists and technicians who are trained in proper sampling, documentation, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed this work plan prior to sample acquisition and will have a copy of the work plan available onsite for reference. Groundwater sampling includes the following activities:

- Assembly and preparation of equipment and supplies;
- Inspection of the monitoring well/point integrity including:
 - Protective cover, cap, and lock,
 - External surface seal and pad,
 - Monitoring point stick-up, cap, and datum reference, and
 - Internal surface seal;

- Groundwater sampling, including:
 - Water level and product thickness measurements,
 - Visual inspection of sample water,
 - Monitoring point casing evacuation, and
 - Sample collection;
- Sample preservation and shipment, including:
 - Sample preparation,
 - Onsite measurement of physical parameters, and
 - Sample labeling;
- Completion of sampling records: and
- Sample disposition.

Detailed groundwater sampling and sample handling procedures are presented in following sections.

3.3.1 Preparation for Sampling

All equipment to be used for sampling will be assembled and properly cleaned and calibrated (if required) prior to arriving in the field. In addition, all record-keeping materials will be gathered prior to leaving the office.

3.3.1.1 Equipment Cleaning

All portions of sampling and test equipment that will contact the sample matrix will be thoroughly cleaned before each use. This includes the Geoprobe[®] sampling tools, sampling pumps, nondisposable bailers, water level probe and cable, test equipment for onsite use, and other equipment or portions thereof that will contact the samples. Given the types of sample analyses to be conducted, the following cleaning protocol will be used:

- Wash with potable water and phosphate-free laboratory detergent (HP-II detergent solutions, as appropriate);
- Rinse with potable water;
- Rinse with isopropyl alcohol;
- Rinse with distilled or deionized water; and
- Air dry.

Any deviations from these procedures will be documented in the field scientist's field notebook and on the groundwater sampling record (Figure 3.5).

Sampling Location Hill AFB

Sampling Dates _____

GROUND WATER SAMPLING RECORD - MONITORING WELL _____

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: _____, 1996 _____ a.m./p.m.

SAMPLE COLLECTED BY: MV/BB of Parsons ES

WEATHER: _____

DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOP OF WELL CASING

MONITORING WELL CONDITION:

☐ LOCKED:

☐ UNLOCKED

WELL NUMBER (IS - IS NOT) APPARENT

STEEL CASING CONDITION IS: _____

INNER PVC CASING CONDITION IS: _____

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 ☐ EQUIPMENT CLEANED BEFORE USE WITH ALCONOX, ISOPROPYL ALCOHOL, AND dH₂O
Items Cleaned (List): _____

2 ☐ PRODUCT DEPTH _____ FT. BELOW DATUM
Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 ☐ WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Appearance: _____

Odor: _____

Other Comments: _____

4 ☐ WELL EVACUATION:

Method: _____

Volume Removed: _____

Observations: Water (slightly - very) cloudy

Water level (rose - fell - no change)

Water odors: _____

Other comments: _____

FIGURE 3.5

GROUNDWATER SAMPLING RECORD

Hill Air Force Base, Utah

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If precleaned, disposable sampling equipment is used, the cleaning protocol specified above will not be required. Laboratory-supplied sample containers will be cleaned and sealed by the laboratory. The type of container provided and the method of container decontamination will be documented in the USEPA mobile laboratory's permanent record of the sampling event.

3.3.1.2 Equipment Calibration

As required, field analytical equipment will be calibrated according to the manufacturers' specifications prior to field use. This applies to equipment used for onsite measurements of DO, pH, electrical conductivity, temperature, ORP, sulfate, nitrate, ferrous iron (Fe^{2+}), and other field parameters listed on Table 3.1.

3.3.2 Well and Monitoring Point Sampling Procedures

Special care will be taken to prevent contamination of the groundwater and extracted samples. The two primary ways in which sample contamination can occur are through contact with improperly cleaned equipment and through cross-contamination due to insufficient cleaning of equipment between wells and monitoring points. To prevent such contamination, the water level probe and cable used to determine static water levels and total well depths will be thoroughly cleaned before and after field use and between uses at different sampling locations according to the procedures presented in Section 3.3.1.1. Dedicated tubing will be used at each well or monitoring point developed, purged, and/or sampled with the sampling pump. Pumps and nondisposable bailers will be decontaminated according to procedures listed in Section 3.3.1.1. In addition to the use of properly cleaned equipment, a clean pair of new, disposable nitrile or latex gloves will be worn by the sampling personnel each time a different well or monitoring point is sampled.

The following paragraphs present the procedures to be followed for groundwater sample collection from groundwater monitoring wells and monitoring points. These activities will be performed in the order presented below. Exceptions to this procedure will be noted in the field scientist's field notebook or on the groundwater sampling record.

3.3.2.1 Preparation of Location

Prior to starting the sampling procedure, the area around the existing wells and new monitoring points will be cleared of foreign materials, such as brush, rocks, and debris. These procedures will prevent sampling equipment from inadvertently contacting debris around the monitoring well/point.

3.3.2.2 Water Level and Total Depth Measurements

Prior to removing water from the monitoring well or PVC-cased monitoring point, the static water level will be measured. An electric water level probe or oil/water interface probe will be used to measure the depth to groundwater below the datum to the nearest 0.01 foot. After measuring the static water level, the water level probe will be slowly lowered to the bottom of the monitoring well/point, and the depth will be measured to the nearest 0.01 foot. Based on these measurements, the volume of water to be purged from the monitoring well/point will be calculated.

3.3.2.3 Monitoring Well/Point Purging

The volume of water contained within the monitoring well/point casing at the time of sampling will be calculated, and at least three times the calculated volume will be removed from the well/point. A peristaltic pump will be used for monitoring well and monitoring point purging, depth and volume permitting, and a Grundfos Redi-Flo II® pump, Waterra® inertial pump, or bailer will be used to purge all monitoring wells or points in which a peristaltic pump cannot be used. All purge waters will be collected for proper disposal by the Base.

If a monitoring well/point is evacuated to a dry state during purging, the monitoring well/point will be allowed to recharge, and the sample will be collected as soon as sufficient water is present in the monitoring well/point to obtain the necessary sample quantity. Sample compositing or sampling over a lengthy period by accumulating small volumes of water at different times to obtain a sample of sufficient volume will not be allowed.

3.3.2.4 Sample Extraction

Dedicated HDPE tubing and a peristaltic pump will be used to extract groundwater samples from monitoring wells/points whenever depth to groundwater permits; otherwise, a bladder pump, a Waterra® inertial pump, or a bailer will be used. The tubing, pump, or bailer will be lowered through the casing into the water gently to prevent splashing. The sample will be transferred directly into the appropriate sample container. The water will be carefully poured down the inner walls of the sample bottle to minimize aeration of the sample.

Unless other instructions are given by the mobile laboratory, sample containers will be completely filled so that no air space remains in the container. Excess water collected during sampling will be disposed of in the same manner as purge water.

3.3.2.5 Grab Sampling

In the event monitoring points are not installed, groundwater grab samples will be collected using the Geoprobe[®] apparatus. To collect these samples, a properly decontaminated, screened probe tip will be driven to the desired sampling depth. As it is driven to depth, the screen will be protected inside the probe rods. After reaching the desired depth, the outer rods will be withdrawn to expose the screen. Purging and sampling procedures will be identical to those for monitoring points. After sampling, the rods and screen will be withdrawn, and the holes will be abandoned as described in Sections 3.1.4 and 3.2.2.4.

3.3.3 Groundwater Sampling at Springs

To determine if CAHs are discharging to the ground surface (and hence creating additional receptor exposure pathways), groundwater emanating from springs, seeps, or other surface water in the study area also will be sampled. Sampling procedures will depend on the manner in which the groundwater discharges to the surface. If possible, sample bottles will be held directly under the discharge area. If a pool of water is present, water will be collected from the bottom of the pool using clean sample jars that will be unscrewed underwater. As needed, a jar will be used to transfer water to preserved sample containers.

3.3.4 Onsite Groundwater Parameter Measurement

As indicated on Table 3.1, many of the groundwater chemical parameters will be measured onsite. Some of the measurements will be made with direct-reading meters, while others will be made using a Hach[®] portable colorimeter in accordance with specific Hach[®] analytical procedures. These procedures are described in the following subsections.

All glassware or plasticware used in the analyses will have been cleaned prior to sample collection by thoroughly washing with a solution of laboratory-grade, phosphate-free detergent (e.g., Alconox[®]) and water, and rinsing with isopropyl alcohol and deionized water to prevent interference or cross-contamination between measurements. If concentrations of an analyte are above the range detectable by the titrimetric or colorimetric methods, the analysis will be repeated by diluting the groundwater sample with distilled water until the analyte concentration falls to a level within the range of the method. All rinseate and sample reagents accumulated during groundwater analysis will be collected in glass containers fitted with screw caps. These waste containers will be clearly labeled as to their contents and carefully stored for proper disposal.

3.3.4.1 Dissolved Oxygen Measurements

DO measurements will be made using a meter with a downhole oxygen sensor or a sensor in a flow-through cell before and immediately following groundwater sample acquisition. When DO measurements are taken in monitoring wells/points that have not yet been sampled, the existing monitoring wells/points will be purged until DO levels stabilize. The lowest stable DO reading will be recorded.

3.3.4.2 pH, Temperature, and Specific Conductance

Because the pH, temperature, and specific conductance of a groundwater sample can change significantly within a short time following sample acquisition, these parameters will be measured in the field in unfiltered, unpreserved, "fresh" water that is collected using the same technique as the samples for laboratory analyses. The measurements will be made in a flow-through cell or a clean glass container separate from those intended for laboratory analysis, and the measured values will be recorded on the groundwater sampling record (Figure 3.5).

3.3.4.3 Oxidation/Reduction Potential

The ORP of groundwater is an indication of the relative tendency of a solution to accept or transfer electrons. Redox reactions in groundwater often are biologically mediated; therefore, the ORP of a groundwater system depends upon and influences rates of biodegradation. ORP can be used to provide real-time data on the location of the contaminant plume, especially in areas undergoing anaerobic biodegradation. The ORP of groundwater within the contaminant plume should be somewhat less than that in an upgradient location.

The ORP of a groundwater sample can change significantly within a short time following sample acquisition and exposure to atmospheric oxygen. As a result, this parameter will be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples for laboratory analyses. The measurements will be made as quickly as possible in a clean glass container separate from those intended for laboratory analysis or in a flow-through cell.

3.3.4.4 Alkalinity Measurements

Alkalinity in groundwater helps buffer the groundwater system against acids generated through both aerobic and anaerobic biodegradation processes. The alkalinity of groundwater will be measured in the field by experienced field personnel via titrimetric analysis using USEPA-approved Hach® Method 8221 (0 to 5,000 mg/L as calcium carbonate) or a similar method. Alkalinity will also be measured in the laboratory using USEPA Method 310.1.

3.3.4.5 Nitrate- and Nitrite-Nitrogen Measurements

Nitrate-nitrogen concentrations are of interest because nitrate can act as an electron acceptor during biodegradation under anaerobic soil or groundwater conditions. Nitrate-nitrogen is also a potential nitrogen source for biomass formation for hydrocarbon-degrading bacteria. Nitrite-nitrogen is an intermediate byproduct in both ammonia nitrification and nitrate reduction in anaerobic environments.

Nitrate- and nitrite-nitrogen concentrations in groundwater will be measured in the field by experienced field personnel via colorimetric analysis using a Hach® DR/700 Portable Colorimeter. Nitrate concentrations in groundwater samples will be analyzed after preparation with Hach® Method 8039 (0 to 30.0 mg/L NO₃). Nitrite concentrations in groundwater samples will be analyzed after preparation with USEPA-approved Hach® Method 8507 (0 to 0.35 mg/L NO₂) or a similar method. Alternatively, samples may be submitted for laboratory analysis using USEPA Method 353.1 or its equivalent.

3.3.4.6 Sulfate and Sulfide Measurements

Sulfate in groundwater is a potential electron acceptor for biodegradation in anaerobic environments, and sulfide results from sulfate reduction. The field scientist will measure sulfate and sulfide concentrations via colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. USEPA-approved Hach® Methods 8051 (0 to 70.0 mg/L SO₄) or and 8131 (0.60 mg/L S²⁻) will be used to prepare samples and analyze sulfate and sulfide concentrations, respectively. Samples may also be submitted for laboratory analysis using a method such as Waters Capillary Electrophoresis Method N-601 or an equivalent.

3.3.4.7 Total Iron, Ferrous Iron, and Ferric Iron Measurements

Iron is an important trace nutrient for bacterial growth, and different states of iron can affect the ORP of the groundwater and visa versa. Iron can act as an electron acceptor for biological metabolism under anaerobic conditions. Iron concentrations will be measured in the field via colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. Hach® Method 8008 (or similar) for total soluble iron (0 to 3.0 mg/L Fe³⁺ + Fe²⁺) and Hach® Method 8146 (or similar) for ferrous iron (0 to 3.0 mg/L Fe²⁺) will be used to prepare and analyze the samples. Ferric iron concentrations will be quantified by subtracting ferrous iron levels from total iron levels.

3.3.4.8 Manganese Measurements

Manganese is a potential electron acceptor under anaerobic environments. Manganese concentrations will be quantified in the field using colorimetric analysis with a Hach® DR/700 Portable Colorimeter. USEPA-approved Hach® Method 8034 (0 to 20.0 mg/L

Mn) or similar will be used for determining manganese concentrations. Sample preparation and disposal procedures are outlined earlier in Section 3.3.3.

3.3.4.9 Carbon Dioxide Measurements

Carbon dioxide concentrations are of interest because carbon dioxide is a byproduct of all biodegradation reactions. In addition, carbon dioxide in groundwater is a potential electron acceptor for methanogenic biodegradation under strong anaerobic conditions. Carbon dioxide concentrations in groundwater will be measured in the field via titrimetric analysis using Hach[®] Method 1436-01 (0 to 250 mg/L as CO₂). Sample preparation and disposal procedures are the same as outlined at the beginning of Section 3.3.3.

3.4 SAMPLE HANDLING FOR LABORATORY ANALYSIS

This section describes the handling of samples from the time of sampling until the samples are delivered to fixed-based laboratory. These procedures are premised on the USEPA NRMRL providing the field and fixed-base laboratory analytical services, and would necessarily be modified as required if other services are contracted by Hill AFB.

3.4.1 Sample Preservation

The laboratory support personnel will add any necessary chemical preservatives prior to filling the sample containers. Samples will be prepared for transportation to the analytical laboratory by placing the samples in a cooler containing ice to maintain a shipping temperature of as close to 4 degrees centigrade (°C) as possible. Samples will be delivered promptly to the field laboratory personnel, who will be responsible for shipment of appropriate samples to the NRMRL in Ada, Oklahoma for analysis.

3.4.2 Sample Container and Labels

Sample containers and appropriate container lids will be provided by the field laboratory (see Appendix B). The sample containers will be filled as described in Sections 3.1.2 and 3.3.2.4, and the container lids will be tightly closed. The sample label will be firmly attached to the container side, and the following information will be legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sample type (e.g., groundwater, soil);
- Sampling date;
- Sampling time;
- Preservatives added;
- Sample collector's initials; and

- Analyses requested.

3.4.3 Sample Shipment

After the samples are sealed and labeled, they will be packaged for transport to the onsite field laboratory. The packaged samples will be delivered by hand to the field laboratory. Delivery will occur as soon as possible after sample acquisition.

The following packaging and labeling procedures will be followed:

- Package sample so that it will not leak, spill, or vaporize from its container;
- Cushion samples to avoid breakage; and
- Add ice to container to keep samples cool.

USEPA personnel will be responsible for repackaging and overnight shipment of samples to the NRMRL in Ada, Oklahoma.

3.4.4 Chain-of-Custody Control

Chain-of-custody documentation for the shipment of samples from the field laboratory to the NRMRL analytical laboratory in Ada, Oklahoma, will be the responsibility of the USEPA field laboratory personnel.

3.4.5 Sampling Records

In order to provide complete documentation of the sampling event, detailed records will be maintained by the field scientist. At a minimum, these records will include the following information:

- Sample location (facility name);
- Sample identification;
- Sample location map or detailed sketch;
- Date and time of sampling;
- Sampling method;
- Field observations of
 - Sample appearance, and
 - Sample odor;
- Weather conditions;
- Water level prior to purging (groundwater samples, only);
- Total monitoring well/point depth (groundwater samples, only);
- Sample depth (soil samples, only);
- Purge volume (groundwater samples, only);
- Water level after purging (groundwater samples, only);

- Monitoring well/point condition (groundwater samples, only);
- Sampler's identification;
- Field measurements of pH, temperature, DO, and specific conductivity (groundwater samples, only); and
- Any other relevant information.

Groundwater sampling information will be recorded on a groundwater sampling form. Figure 3.5 shows an example of the groundwater sampling record. Soil sampling information will be recorded in the field log book.

3.4.6 Laboratory Analyses

Laboratory analyses will be performed on all groundwater and soil samples as well as the QA/QC samples described in Section 4. The analytical methods for this sampling event are listed in Table 3.1. Prior to sampling, USEPA NRMRL personnel will provide a sufficient number of analyte-appropriate sample containers for the samples to be collected. All containers, preservatives, and shipping requirements will be consistent with USEPA protocol or those listed in Appendix E of this plan.

USEPA laboratory support personnel will specify the necessary QC samples and prepare appropriate QC sample containers. For samples requiring chemical preservation, preservatives will be added to containers by the laboratory or USEPA NRMRL field personnel. Containers, ice chests with adequate padding, and cooling media will be provided by USEPA NRMRL laboratory personnel. Sampling personnel will fill the sample containers and return the samples to the field laboratory.

3.5 AQUIFER TESTING

3.5.1 Slug Tests

Slug tests may be conducted on selected previously installed 2-inch-ID monitoring wells to estimate the hydraulic conductivity of unconsolidated deposits at the site. This information is required to estimate the velocity of groundwater and contaminants in the shallow saturated zone. A slug test is a single-well hydraulic test used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug tests can be used for both confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft^2/day). Slug testing can be performed using either a rising head or a falling head test. At this site, rising head and falling head methods will be used in sequence.

3.5.1.1 Definitions

- **Hydraulic Conductivity (K).** A proportionality constant that is the quantitative measure (L/t) of the ability of porous media to transmit water at the existing

kinematic viscosity; defined as the volume of water that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

- **Transmissivity (T).** The rate (L^2/t) at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient. It is the product of the hydraulic conductivity and the saturated thickness.
- **Slug Test.** Two types of testing are possible: rising head and falling head tests. A slug test consists of adding a slug of water or a solid cylinder of known volume to the well to be tested or removing a known volume of water or cylinder and measuring the rate of recovery of water level inside the well. The slug of a known volume acts to raise or lower the water level in the well.
- **Rising Head Test.** A test used in an individual well within the saturated zone to estimate the hydraulic conductivity of the surrounding formation by lowering the water level in the well and measuring the rate of recovery of the water level. The water level may be lowered by pumping, bailing, or removing a submerged slug from the well.
- **Falling Head Test.** A test used in an individual well to estimate the hydraulic conductivity of the surrounding formation by raising the water level in the well by insertion of a slug or quantity of water, and then measuring the rate of drop in the water level.

3.5.1.2 Equipment

The following equipment will be used to conduct a slug test:

- Teflon[®], PVC, or metal slugs;
- Nylon or polypropylene rope;
- Electric water level indicator;
- Pressure transducer/sensor;
- Field logbook/forms; and
- Automatic data-recording instrument (such as the Hermit Environmental Data Logger[®], In-Situ, Inc. Model SE1000B, or equivalent).

3.5.1.3 General Test Methods

Slug tests are accomplished by either removing a slug or quantity of water (rising head) or introducing a slug (falling head), and then allowing the water level to stabilize while taking water level measurements at closely spaced time intervals.

Because hydraulic testing will be completed on existing wells, it will be assumed that the wells were properly developed and that water levels have stabilized. Slug testing will proceed only after multiple water level measurements over time show that static water levels are in equilibrium. During the slug test, the water level change should be influenced only by the introduction (or removal) of the slug volume. Other factors, such as inadequate well development or extended pumping may lead to inaccurate results; in addition, slug tests will not be performed on wells with LNAPL. The field scientist will determine when static equilibrium has been reached in the well. The pressure transducer, slugs, and any other downhole equipment will be decontaminated prior to and immediately after the performance of each slug test using the procedures described in Section 3.3.1.1.

3.5.1.4 Falling Head Test

The falling head test is the first step in the two-step slug testing procedure. The following steps describe procedures to be followed during performance of the falling head test.

1. Decontaminate all downhole equipment prior to initiating the test.
2. Open the well. Where wells are equipped with watertight caps, the well should be unsealed at least 24 hours prior to testing to allow the water level to stabilize. The protective casing will remain locked during this time to prevent vandalism.
3. Prepare the aquifer slug test data form (Figure 3.6) with entries for:
 - Borehole/well number,
 - Project number,
 - Project name,
 - Aquifer testing team,
 - Climatic data,
 - Ground surface elevation,
 - Top of well casing elevation,

Aquifer Slug Test Data Sheet

Location <u>Hill AFB</u>	Client <u>AFCEE</u>	Well No. _____
Job No. _____	Field Scientist _____	Date _____
Water Level _____	Total Well Depth _____	
Measuring Datum <u>TOC</u>	Elevation of Datum _____	
Weather _____	Temp _____	
Comments _____		

[illegible]**FIGURE 3.6**

AQUIFER TEST DATA FORM

Hill Air Force Base, Utah

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- Identification of measuring equipment being used,
 - Page number,
 - Static water level, and
 - Date.
4. Measure the static water level in the well to the nearest 0.01 foot.
 5. Lower the decontaminated pressure transducer into the well and allow the displaced water to return to its static level. This can be determined by periodic water level measurements until the static water level in the well is within 0.01 foot of the original static water level.
 6. Lower the decontaminated slug into the well to just above the water level in the well.
 7. Turn on the data logger and quickly lower the slug below the water table, being careful not to disturb the pressure transducer. Follow the owner's manual for proper operation of the data logger.
 8. Terminate data recording when the water level stabilizes in the well. The well will be considered stabilized for termination purposes when it has recovered 80 to 90 percent from the initial displacement.

3.5.1.5 Rising Head Test

After completion of the falling head test, the rising head test will be performed. The following steps describe the rising head slug test procedure.

1. Measure the water level in the well to the nearest 0.01 foot to ensure that it has returned to the static water level.
2. Initiate data recording and quickly withdraw the slug from the well. Follow the owner's manual for proper operation of the data logger.
3. Terminate data recording when the water level stabilizes in the well, and remove the pressure transducer from the well and decontaminate. The well will be considered stabilized for termination purposes when it has recovered 80 to 90 percent from the initial displacement.

3.5.1.6 Slug Test Data Analysis

Data obtained during slug testing will be analyzed using AQTESOLV™ (Geraghty & Miller, Inc., 1994), which employs the method of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions.

3.5.2 Downhole Flowmeter Testing

Downhole flowmeter tests may be conducted to investigate the relative vertical distribution of horizontal hydraulic conductivity in upper portion of saturated zone and to identify any zones of high hydraulic conductivity. To do so, it is recommended that field personnel perform electromagnetic borehole flowmeter surveys in up to five previously installed monitoring wells using the methodology of Molz *et al.* (1994). Additional wells may be surveyed depending on availability and preliminary test results. These tests will be done to identify fast flow zones that appear to accelerate contaminant migration within the shallow groundwater system. Preferably, wells to be flow tested will be those that are also slug tested for hydraulic conductivity.

3.5.2.1 Experiment Design

Flowmeter measurements will be performed at 1- to 3-foot intervals below the water table during both ambient conditions and induced flow conditions. The test data will be analyzed using the methods described by Molz *et al.* (1994) to define the relative distribution of horizontal hydraulic conductivity within the screened interval of each well. Final results will be presented in tabular and graphical forms and accompanied by appropriate interpretation and discussion. Estimates of bulk hydraulic conductivity from previous aquifer tests or results of the single-well tests conducted during this survey will be used to estimate the absolute hydraulic conductivity distribution at each well.

3.5.2.2 Procedure

The borehole flowmeter will be calibrated prior to departure for Hill AFB. The 0.5-inch-ID and 1.0-inch-ID probes will be calibrated using a range of volumetric flow rates potentially applicable to this demonstration [e.g., approximately 0.04 liters per minute (L/min) to 10 L/min].

The flowmeter survey will be conducted in each well using the following procedure:

1. Water level, organic liquid NAPL interfaces (if present), and total depth (TD) will be measured prior to test initiation.
2. Depending on site conditions, flowmeter measurements using the 0.5-inch-ID probe will be obtained at 1- to 3-foot intervals starting at TD and proceeding up the well under static (ambient) conditions.
3. A short-term, single-well pumping test will be conducted in the test well to stress the aquifer. Drawdown will be measured and recorded using an electronic datalogger with a pressure transducer. The groundwater extraction rate will be monitored and adjusted, as necessary, to maintain constant flow. Extracted groundwater will be contained for disposal by site personnel. It is estimated that

extraction rates may range from less than 1 L/min to approximately 10 L/min, and that the test duration may range from 1 to 4 hours.

4. Upon stabilization of the flow rate, the profile of vertical flow will be obtained using the 1.0-inch-ID probe at the same elevations occupied during the ambient profile.
5. Data collected during the tests will be analyzed to estimate relative distribution of flow to the wells and the relative hydraulic conductivity distribution at each location.

All downhole test equipment will be properly decontaminated between tests at different monitoring wells.

3.5.3 Spring Discharge Rate Measurement

Where possible, volumetric rates of groundwater discharge at springs and seeps also will be measured. As with spring sampling, the method used to determine discharge rates will depend on the nature of the spring.

3.6 MICROCOSM STUDIES

Microcosm studies may be performed on selected soil samples collected at OU 2 to confirm biodegradation of CAHs. Because microcosm studies are time-consuming and expensive, they should be undertaken only at sites where there is considerable uncertainty concerning the biodegradation of CAHs based on soil and groundwater samples alone. If biodegradation is occurring, these microcosms also will help determine which mechanisms of biodegradation are operating at the site.

If properly designed, implemented, and interpreted, microcosm studies can provide very convincing documentation of the occurrence of natural bioremediation. They are the only "line of evidence" that allows an unequivocal mass balance on the biodegradation of environmental contaminants. If the microcosm study is properly designed, the results will be easy for decision makers with differing technical backgrounds to interpret. The results of a microcosm study are strongly influenced by the nature of the geological material submitted for the study, the physical properties of the microcosm, the sampling strategy, and the duration of the study.

3.6.1 Microcosm Sample Collection

Saturated soil and groundwater samples for microcosm construction will be collected using the Geoprobe[®] system. Ideally, samples collected for microcosms will meet the following conditions: 1) soils and groundwater will be collected a minimum of 3 feet below the groundwater surface to minimize oxygen contamination, 2) TCE concentrations in the groundwater/pore water will be greater than 1 mg/L to guarantee

compound resolution throughout the microcosm studies, and 3) only sands or other granular materials should be used for microcosm construction. In the event that soils are highly plastic in the areas selected for microcosm collection, additional attempts at sample collection must be performed in the vicinity to locate soils with permeabilities greater than a fine sand. If any of these conditions are not met, microcosm study results may be compromised.

The soil cores will be retained within brass, stainless steel, clear acetate, or Teflon[®] liners inside the sampling barrel. The soil sample can then be extruded from the liners for logging, or the liners can be capped and undisturbed samples submitted to the analytical laboratory for testing and microcosm construction. Transferring the saturated aquifer media from the soil sampling device will be conducted in a manner that minimizes environmental exposure and maintains the original physical, chemical, and biological characteristic. The greater the care taken to maintain *in situ* conditions in the microcosm cores, the greater correlation the microcosm data will have to the field scale. The soil sampling device will be retracted quickly from the ground to reduce any potential soil and groundwater loss from the downhole end the sampling apparatus. Furthermore, rapid extraction from the subsurface will help minimize aeration of samples taken from anoxic zones.

Additional groundwater will be collected during soils acquisition. Groundwater will be used to displace the headspace in soil collection jars. Additional groundwater volumes also may be needed for microcosm construction at the USEPA NRMRL in Ada, Oklahoma. Shallow groundwater will be extracted with peristaltic pumps, bailers, or other devices, depending upon site conditions.

All soil and groundwater samples will be collected and stored to minimize oxygen contamination. The jars containing site media will be cooled to 4 degrees Celsius (°C) and packed in a manner to prevent accidental breakage during shipment. Coolers will be shipped via an overnight courier to be received by the laboratory the morning following sampling.

3.6.2 Microcosm Construction and Sampling

Trained personnel will be responsible for construction and sampling of the microcosms. Standard microcosm procedures, including use of sterilized controls, will be followed to complete this study. These procedures will follow those general procedures as outlined at the beginning of Section 3.6.

Batch microcosms that are sacrificed for each analysis usually give better results than column microcosms or batch microcosms that are sampled repetitively. For statistical reasons, at least three microcosms should be sampled at each time interval. If a first-order rate law is assumed and there is no lag, a geometric time interval for sampling

should be the most efficient. An example would be sampling after 0 week, 2 weeks, 1 month, 2 months, 4 months, and 8 months. As a practical matter, long lags frequently occur, and the rate of bioremediation after the lag is rapid; therefore, a simple linear time scale is most likely to give valid results. Sampling intervals may be adjusted as the data are collected.

Microcosms are inherently time consuming. At field scale, the residence time of a plume may be several years to decades, and slow rates of transformation may have a considerable environmental significance. A microcosm study that lasts only a few weeks or months may not have the resolution to detect slow changes that are still of environmental significance. Further, microcosms often show a pattern of sequential utilization, with certain contaminants degrading first, and others degrading at a later time. Degradation of some compounds may be delayed by as much as a year.

The batch microcosms should have approximately the same ratio of solids to water as the original material. Most of the microbes are attached to solids. Therefore, if a microcosm has excess water, and the contaminant is mostly in the aqueous phase, the microbes must process a great deal more contaminant to produce the same relative change in the contaminant concentration. The kinetics at the field scale would be underestimated.

As a practical matter, batch microcosms with an optimal solids-to-water ratio, sampled every 2 months in triplicate for up to 18 months, can resolve biodegradation losses from abiotic losses with a rate detection limit of 0.001 to 0.0005 per day. Many plumes show significant attenuation of contamination at field-calibrated rates that are slower than these detection limits. The most appropriate use of microcosms is to document that contaminant attenuation is largely a biological process. Rate constants for modeling purposes are more appropriately acquired from field-scale studies.

SECTION 4

QUALITY ASSURANCE/QUALITY CONTROL

Field QA/QC procedures appropriate to a typical site investigation should be followed for the RNA demonstration. If necessary, these procedures should follow appropriate regulatory guidelines, or should be agreed upon by all involved parties. The following suggested procedures are typically suitable for an RNA demonstration.

Field QA/QC procedures will include collection of field duplicates and rinseate, field and trip blanks; decontamination of all equipment that contacts the sample medium before and after each use; use of analyte-appropriate containers; and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., groundwater), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used, and sample containers will be packaged in coolers with ice to maintain a temperature of as close to 4°C as possible.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature. Field QC samples will be collected in accordance with the program described below, and as summarized in Table 4.1.

QA/QC sampling will include collection and analysis of duplicate groundwater and replicate soil samples, rinseate blanks, field/trip blanks, and matrix spike samples. Internal laboratory QC analyses will involve the analysis of laboratory control samples (LCSs) and laboratory method blanks (LMBs). QA/QC objectives for each of these samples, blanks, and spikes are described below.

Duplicate water and replicate soil samples will be collected at a frequency of 1 for every 10 or fewer samples of similar matrix. Soil and groundwater samples collected with the Geoprobe® sampler should provide sufficient volume for some replicate/duplicate analyses. Refer to Table 3.1 and Appendix E for further details on sample volume requirements.

TABLE 4.1
QA/QC SAMPLING PROGRAM
Hill Air Force Base, Utah

QA/QC Sample Types	Frequency to be Collected and/or Analyzed	Analytical Methods
Duplicates/Replicates	5 Groundwater and 1 Soil Samples (10%)	VOCs
Rinseate Blanks	3 Samples (5% of Groundwater Samples)	VOCs
Field Blanks	3 Samples (5% of Groundwater Samples)	VOCs
Trip Blanks	One per shipping cooler containing VOC samples	VOCs
Matrix Spike Samples	Once per sampling event	VOCs
Laboratory Control Sample	Once per method per medium	Laboratory Control Charts (Method Specific)
Laboratory Method Blanks	Once per method per medium	Laboratory Control Charts (Method Specific)

One rinseate sample will be collected for every 20 or fewer groundwater samples collected from existing wells. Because disposable bailers may be used for this sampling event, the rinseate sample will consist of a sample of distilled water poured into a new disposable bailer and subsequently transferred into a sample container provided by the laboratory. Rinseate samples will be analyzed for VOCs only.

A field blank will be collected for every 20 or fewer groundwater samples (both from groundwater monitoring point and groundwater monitoring well sampling events) to assess the effects of ambient conditions in the field. The field blank will consist of a sample of distilled water poured into a laboratory-supplied sample container while sampling activities are underway. The field blank will be analyzed for VOCs.

A trip blank will be analyzed to assess the effects of ambient conditions on sampling results during the transportation of samples. The trip blank will be prepared by the laboratory. A trip blank will be transported inside each cooler which contains samples for VOC analysis. Trip blanks will be analyzed for VOCs.

Matrix spikes will be prepared in the laboratory and used to establish matrix effects for samples analyzed for VOCs. LCSs and LMBs will be prepared internally by the laboratory and will be analyzed each day samples from the site are analyzed. Samples will be reanalyzed in cases where the LCS or LMB are out of the control limits. Control charts for LCSs and LMBs will be developed by the laboratory and monitored for the analytical methods used (see Table 3.1).

SECTION 5

DATA ANALYSIS AND REPORT

Data collected during the field effort (protocol parameter sampling and potential intrusive work) will be analyzed using a variety of methods. For example, isopleth maps of CAHs, degradation products, and alternate electron acceptors and donors will be used to evaluate the occurrence and mechanisms of biodegradation at the site. The Thiessen method will be used to estimate contaminant mass in the plume using data from the latest sampling event and from selected previous sampling events. The Thiessen method also may be used to evaluate movement of the center of mass of the CAH plume over time, as presented by Dupont *et al.* (1996a and 1996b). This information will be useful in determining how the plume has changed over time and if it is stable. Assuming a continuing source of contamination does not exist, contaminant mass should diminish over time, if RNA is occurring. The DNAPLs at OU 2 are a continuing source of contamination. However, the containment wall currently being constructed could effectively impede contaminant migration from the source area DNAPLs. The potential impacts of this remedial action on RNA will be evaluated. In addition, site contaminant data will be used to determine rates of contaminant mass loss, and in conjunction with microcosm data, to determine rates of biodegradation. The data also will be used to estimate contaminant mass flux through specified areas and to estimate volumetric mass discharge.

After the data evaluation and analysis, numerical and/or analytical groundwater models will be used to evaluate the fate and transport of chlorinated solvents dissolved in groundwater at the site. The contaminant fate and transport modeling effort has three primary objectives: 1) predict the future extent and concentration of dissolved contaminant plumes by modeling the effects of advection, dispersion, sorption, and biodegradation; 2) assess the possible exposure and risk to potential downgradient receptors; and 3) to provide technical support for selection of RNA as a viable remedial alternative.

Based on model predictions of contaminant concentrations and distribution through time, and on potential exposure pathways, the potential for receptors to be exposed to contaminant concentrations that could threaten human health and the environment will be assessed. If it is apparent that RNA of CAHs at the site is sufficient to reduce the

potential threat to human health and the environment to acceptable levels, an RNA option will be recommended, and a site-specific LTM plan will be devised. A comprehensive report detailing the fieldwork and analysis of RNA will be prepared.

If the RNA remedial option is deemed inappropriate for sole use at the site or use in conjunction with other potential remedial options, institutional controls such as groundwater or land use restrictions could be evaluated. If institutional controls are inappropriate, planned or potential engineered remedial designs are an option. The reduction in dissolved contaminant concentrations that should result from remedial activities could be used to produce new input files for the groundwater models. The models could then be used to predict the plume mass reduction that should result from remedial actions.

SECTION 6

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FINAL

APPENDIX A

**ANALYTES DETECTED IN GROUNDWATER AT OU 2
AUGUST 1995 AND FEBRUARY 1996**

Table A.1 --Summary of Analytical Results for OU2 Groundwater Sampling, August 1995

[illegible]

U = Indicates the compound was not detected at or above the reporting limit.
The number adjacent to the "U" is the reporting limit.
B = The reported value obtained was less than the contract reporting limit, but greater than or equal to the instrument detection limit.

Table A.1 --Summary of Analytical Results for OU2 Groundwater Sampling, August 1995

Station	Sample ID	Date Collected	U2-25(D)																U2-308				U2-310				U2-312				U2-324																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
			U2-25(H028)																U2-307(D)				U2-307(H011)				U2-307(H012)				U2-307(H013)				U2-307(H003)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
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SPECIFIC CONDUCTANCE	SUSPENDED SOLIDS (RESIDUE, NON-FILTERABLE)	umhos/cm	880	700	1130	580	1020	1100	890	910	1020	560	544	830	790	500																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				

OU2 - Offsite Field Sample
 U = Indicates the compound was not detected at or above the reporting limit.
 B = The reported value obtained was less than the contract reporting limit.
 See greater than or equal to the instrument detection limit.

Table A.1 --Summary of Analytical Results for OU2 Groundwater Sampling, August 1995

Station	U2-25(D)	U2-27	U2-29	U2-36	U2-37	U2-38	U2-41	U2-42	U2-302	U2-307	U2-307(D)	U2-308	U2-310	U2-312	U2-324
Sample ID	U2952H028	U2952H016	U2952H014	U2952H009	U2952H010	U2952H024	U2952H017	U2952H022	U2952H005	U2952H011	U2952H012	U2952H015	U2952H013	U2952H008	U2952H003
Date Collected	31-Aug-95	30-Aug-95	29-Aug-95	29-Aug-95	29-Aug-95	30-Aug-95	30-Aug-95	30-Aug-95	29-Aug-95	29-Aug-95	29-Aug-95	30-Aug-95	29-Aug-95	29-Aug-95	29-Aug-95
VOC (SW8310)															
1,1,1-TRICHLOROETHANE	3	U1	U1	U1	U1	1.3	7.7	U1	U1	U1	U1	U1	U1	U1	U1
1,1,2,2-TETRACHLOROETHANE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
1,1,2-TRICHLOROETHANE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
1,1-DICHLOROETHANE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
1,1-DICHLOROETHENE	U1	U1	U1	U1	U1	U1	1	U1	U1	U1	U1	U1	U1	U1	U1
1,2-DICHLOROBENZENE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
1,2-DICHLOROETHANE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
1,2-DICHLOROPROPANE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
1,3-DICHLOROBENZENE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
1,4-DICHLOROBENZENE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
BROMOFORM	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
CARBON TETRACHLORIDE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
CHLOROBENZENE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
CHLOROETHANE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
CHLOROFORM	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
CHLOROMETHANE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
cis-1,3-DICHLOROPROPENE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
DICHLORODIFLUOROMETHANE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
METHYLENE CHLORIDE	U5	U5	U5	U5	U5	U5	U5	U5	U5	U5	U5	U5	U5	U5	U5
TETRACHLOROETHYLENE(PCE)	18	U1	U1	U1	U1	U1	3.9	U1	U1	U1	U1	U1	U1	U1	U1
trans-1,2-DICHLOROETHENE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
trans-1,3-DICHLOROPROPENE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
trans-1,3-DICHLOROETHYLENE (TCE)	450	U1	U1	U1	U1	120	480	62	U1	U1	U1	9.9	U1	U1	U1
TRICHLOROFLUOROMETHANE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
VINYL CHLORIDE	U1	U1	U1	U1	U1	U1	3.7	U1	U1	U1	U1	U1	U1	U1	U1
Polynuclear Aromatic Hydrocarbons (SW8310)															
ACENAPHTHENE	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2
ACENAPHTHYLENE	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2
ANTHRACENE	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2
BENZOAANTHRACENE	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2
BENZO(a)PYRENE	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1
BENZO(b)FLUORANTHENE	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1
BENZO(g,h,i)PERYLENE	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2
BENZO(k)FLUORANTHENE	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1	U0.1
BROMODICHLOROMETHANE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
BROMOMETHANE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
CHRYSENE	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2
DIBENZO(a,h)ANTHRACENE	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2
DIBROMOCHLOROMETHANE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
FLUORANTHENE	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2
FLUORENE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
INDENO(1,2,3-cd)PYRENE	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2	U0.2
NAPHTHALENE	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2
PHENANTHRENE	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1	U1
PYRENE	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2	U2

U1 = Duplicate Field Sample
 U = Indicates the compound was not detected at or above the reporting limit.
 The number adjacent to the "U" is the reporting limit.

FINAL

APPENDIX B

**ANALYTICAL METHODS, DATA USE, AND PACKAGING
REQUIREMENTS FOR SOIL AND GROUNDWATER SAMPLES**

APPENDIX B

ANALYTICAL METHODS, DATA USE, AND PACKAGING

REQUIREMENTS FOR SOIL AND GROUNDWATER SAMPLES

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil	Total volatile and extractable hydrocarbons,	Gas chromatography (GC) method SW801.5 [modified]	Handbook method; reference is the California LUFT manual	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Aromatic and Chlorinated hydrocarbons (BTX, PCE, TCE, DCE, VC)	Purge and trap GC method SW8240	Handbook method modified for field extraction of soil using methanol	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Total organic carbon (TOC)	SW9060 modified for soil samples	Procedure must be accurate over the range of 0.01–15 percent TOC	The rate of migration of petroleum contaminants in groundwater is dependent upon the amount of TOC in the aquifer matrix.	At initial sampling	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Moisture	ASTM D-2216	Handbook method	Data are used to correct soil sample analytical results for moisture content (e.g., report results on a dry weight basis).	Each soil sampling round	Use a portion of soil sample collected for another analysis	Fixed-base

APPENDIX B (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Aromatic and chlorinated hydrocarbons (BTEX, trimethylbenzene isomers, PCE, TCE, DCE, VC, chloromethane, chloroform, other relevant compounds)	Methods SW8010/8020 or SW8240	Handbook methods; analysis may be extended to higher molecular weight alkylbenzenes	Method of analysis for BTEX & CAHs, which are the primary target analytes for monitoring natural attenuation; BTEX & CAH concentrations must also be measured for regulatory compliance; trimethylbenzenes are used to monitor BTEX plume dilution if degradation is primarily anaerobic. Chloromethane and chloroform are indicators of CAH contamination by aerobic pathways.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base
Water	Polycyclic aromatic hydrocarbons (PAHs) (optional)	GC/mass spectroscopy method SW8270; high-performance liquid chromatography method SW8310	Analysis needed only when required for regulatory compliance.	PAHs are components of fuel and are typically analyzed for regulatory compliance; data on their concentrations are not used currently in the evaluation of natural attenuation.	As required by regulations	Collect 1 L of water in a glass container; cool to 4°C	Fixed-base
Water	Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure.	The oxygen concentration is a data input to the Bioplume model; concentrations less than 1 mg/L generally indicate an anaerobic pathway.	Each sampling round	Measure dissolved oxygen on site using a flow-through cell	Field

APPENDIX B (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Nitrate	IC method E300	Method E300 is a Handbook method.	Substrate for microbial respiration if oxygen is depleted.	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; add H_2SO_4 to pH 2, cool to 4°C	Fixed-base
Water	Iron (II) (Fe^{+2})	Colorimetric Hach Method # 8146	Filter if turbid.	May indicate an anaerobic degradation process due to depletion of oxygen, and nitrate.	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Sulfate (SO_4^{-2})	IC method E300	Method E300 is a Handbook method, if this method is used for sulfate analysis, do not use the field method.	Substrate for anaerobic microbial respiration	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base
Water	Sulfate (SO_4^{-2})	Hach method # 8051	Colorimetric, if this method is used for sulfate analysis, do not use the fixed-base laboratory method.	Same as above	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Field
Water	Methane, ethane, and ethene	Kampbell <i>et al.</i> , 1989 or SW3810 Modified	Method published by researchers at the US Environmental Protection Agency.	The presence of CH_4 suggests BTEX or other carbon degradation via methanogenesis. Ethane and ethene data are used where chlorinated solvents are suspected of undergoing anaerobic biological transformation.	Each sampling round	Collect water samples in 50 mL glass serum bottles with butyl gray/Teflon-lined caps; add H_2SO_4 to pH 2, cool to 4°C	Fixed-base

APPENDIX B (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Carbon dioxide	Hach test kit model CA-23; Chemetrics Method R-1910	Titrimetric; alternate method	The presence of free CO ₂ dissolved in groundwater is unlikely because of the carbonate buffering system of water, but if detected, the CO ₂ concentrations should be compared with background levels to determine if they are elevated; elevated concentrations of CO ₂ could indicate biodegradation of dissolved contaminants.	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Alkalinity	Hach Alkalinity test kit model AL AP MG-L	Phenolphthalein method	General water quality parameter used (1) as a marker to verify that all site samples are obtained from the same groundwater system and (2) to measure the buffering capacity of groundwater.	Each sampling round	Collect 100 mL of water in glass container	Field
Water	Oxidation-reduction potential (ORP)	A2580B	Measurements made with electrodes; results are displayed on a meter; protect samples from exposure to oxygen. Report results against a silver/silver chloride reference electrode	The ORP of groundwater influences and is influenced by the nature of the biologically mediated degradation of contaminants; the ORP of groundwater may range from more than 800 mV to less than -400 mV.	Each sampling round	Collect 100-250 mL of water in a glass container, filling container from bottom; analyze immediately	Field

APPENDIX B (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	pH	Field probe with direct reading meter.	Field	Aerobic and anaerobic processes are pH-sensitive.	Each sampling round	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Water	Temperature	Field probe with direct reading meter.	Field only	Well development.	Each sampling round	Not Applicable	Field
Water	Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system.	Each sampling round	Collect 100–250 mL of water in a glass or plastic container	Field
Water	Chloride	Mercuric nitrate titration A4500-Cl ⁻ C	Ion chromatography (IC) method E300 or method SW9050 may also be used	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system; elevated concentrations may also indicate biodegradation of CAHs.	Each sampling round	Collect 250 mL of water in a glass container	Fixed-base
Water	Chloride (optional, see data use)	Hach Chloride test kit model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field.	Each sampling round	Collect 100mL of water in a glass container	Field
Water	Total Organic Carbon		Laboratory	Used to classify plume and to determine if CAH biodegradation is possible in the absence of anthropogenic carbon.	Each sampling round	Collect 100 mL of water in a glass container, cool	Laboratory

APPENDIX B (concluded)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
ADDITIONAL (OPTIONAL) ANALYSES							
Water	Biochemical Oxygen Demand	EPA Method 405.1			Each sampling round	Collect 2 L of water in a glass container, cool to be determined	Laboratory
Water	Hydrogen (H ₂)		Relatively new analysis; data useful for evaluating biodegradation processes operating at a given time	Indicator of terminal electron-accepting processes operating at a site.	Each sampling round		
Water	Oxygenates (including methanol and acetone)	Optional; SW 8015 Modified			Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Laboratory
Water	Alcohols, ethers, and acetic acids	Optional; SW 8015 Modified		Optional carbon sources for biodegradation.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Laboratory
Water	Acetaldehydes	Optional; GC/MS method to be determined			Each sampling round	to be determined	Laboratory
Water	Aliphatic Fatty Acids	Optional; GC/MS method to be determined		Byproducts of biodegradation processes; indicators of biodegradation and cometabolism.	Each sampling round	to be determined	Laboratory
Water	Organic Acids	Optional; GC/MS method to be determined		Optional carbon sources and byproducts of biodegradation processes.	Each sampling round	to be determined	Laboratory

NOTES:

- * Analyses other than those listed in this table may be required for regulatory compliance.
1. "Hach" refers to the Hach Company catalog, 1990.
 2. "A" refers to *Standard Methods for the Examination of Water and Wastewater*, 18th edition, 1992.
 3. "E" refers to *Methods for Chemical Analysis of Water and Wastes*, USEPA, 1983.
 4. "Protocols" refers to the AFCEE Environmental Chemistry Function Installation Restoration Program Analytical Protocols, 11 June 1992.
 5. "Handbook" refers to the AFCEE Handbook to Support the Installation Restoration Program (IRP) Remedial Investigations and Feasibility Studies (RI/FS), September 1993.
 6. "SW" refers to the *Test Methods for Evaluating Solid Waste, Physical, and Chemical Methods*, SW-846, USEPA, 3rd edition, 1986.
 7. "ASTM" refers to the *American Society for Testing and Materials*.
 8. "LUFT" refers to the State of California Leaking Underground Fuel Tank Field Manual, 1988 edition.